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Research on Building Education & Workforce Capacity in Systems Engineering

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EXECUTIVE SUMMARY

RT-19A, *Research on Building Education & Workforce Capacity in Systems Engineering*, is the second phase of a two-year research study whose goal is to understand the impact of diverse capstone courses that exposed undergraduate and graduate engineering majors to authentic Department of Defense (DoD) problems and engaged them in the learning and practice of systems engineering, and outcomes related to systems engineering careers and interest. Over an 18-month, three-phase effort from April 2011 to September 2012 that encompassed course planning, implementation, and analysis, participating RT-19A schools and the research team explored methods and approaches to augment the systems engineering workforce for future DoD and related industry workforce needs.

The strategic goals addressed by this research are twofold: to understand the institutional challenges and successes in the adoption of core elements of successful systems engineering capstone projects; and to examine the contexts and program characteristics leading to highly successful student team-developed products and artifacts that respond to authentic Department of Defense (DoD) problem areas. To produce the following report, the research team gathered data from student pre and post surveys in order to analyze the impact of the systems engineering capstone project on student learning of systems engineering, student interest in systems engineering careers, and student awareness/interest in authentic DoD problems. In addition, this report also contains input gathered from surveys submitted by PIs and mentors, and from observations and interviews taken from a systems engineering capstone conference June 2012.

Institutions were selected for participation through a competitive application process based on a set of criteria developed in consultation with the sponsor, and partners were awarded a subcontract for the development, implementation, analysis, and reporting on their systems engineering capstone project. Altogether, sixteen schools were selected to participate in the RT-19A effort: six Systems Engineering Research Center (SERC) member universities, four service academies, and six partner schools. In the first year of this study fifteen systems engineering capstone courses were developed and implemented at six military institutions and eight civilian universities affiliated with the Systems Engineering Research Center. Ten of those schools returned to participate in this year's effort.

The capstone courses were organized around SPRDE-SE systems engineering competencies and selection of Department of Defense problem areas. Five topic areas illustrating authentic DoD problems were presented for student teams' projects. Problem areas #2 and 4 (see Table 3 for more complete description) were the most researched topics, with more than half the projects addressing one of the two problem areas. Selection of problem areas was based on student research interest, expertise of participating faculty, or the decision to continue capstone designs from the prior year. Institutions organized their teams in different ways. The most common structure included several teams each working on a subsystem.

According to final reports submitted by principal investigators, 306 and 339 students participated in RT-19A-sponsored systems engineering capstone courses in the fall 2011 and spring 2012 semesters, respectively. Many institutions enrolled the same students for both semesters. An estimated 198 students worked on DoD problem areas, or 64.7% of students enrolled in the spring courses. Of these, 154 were undergraduates, 38 were graduate students, and 1 was a postgraduate student. The population was over three-quarters male and 20% female. Thirty percent of the students surveyed were systems engineering majors, followed by mechanical engineering majors (25%). Other student majors included electrical, industrial, software, and civil engineering; computer science; and engineering management. Only half of the students reported working in multidisciplinary teams prior to their capstone experience.

Fifty-one faculty members participated in the development, delivery, and assessment of RT-19A courses, almost the same number as participated in RT-19 (50), with the highest percentage from Mechanical Engineering departments, followed by Systems Engineering. This year's faculty also came from Industrial, Electrical, Civil, Mechanical, Systems, Software, Ocean Engineering, and Computer Science. Eight schools included faculty participants from more than one engineering discipline.

Over the course of two semesters, students enrolled in the capstone courses created a number of physical prototypes, summarized in Table 5, that responded to their DoD problem areas. Overall, 75% of responding students felt their team produced projects that successfully fulfilled requirements; showed proof-of-concept; encouraged multidisciplinary, intergroup communication and coordination; and demonstrated their understanding of systems engineering concepts, from the initial design and requirements determination stages, to final prototype testing. Of those who did not feel their projects were successful, lack of resources and time were the most frequently cited reasons. The students attributed parts delays; the inability to build an operational prototype or to complete specific phases of the project, such as testing; communication between team members from different disciplines; and communication over distance as project problems. PIs cited technical issues with modifying off-the-shelf (COTS) software and hardware (e.g., Microsoft Kinect, batteries); time management; delays in parts acquisition; budget limits; and funding delays as challenges to student prototype construction.

A goal of the systems engineering capstone courses implemented in RT-19A was to increase student awareness of the diversity of problem areas addressed by the DoD. From pre- to post-survey, there was an increase from 14% to 18% of students who listed what were clearly systems engineering issues ("requirements management," "project scheduling," "systems integration," "predictive decision algorithms"). Research related to military field needs (materials research, troop protection, expeditionary housing, water filtration, improved IED detection, and lightweight armor) increased the most in students' awareness.

Another goal of the systems engineering capstone courses was to increase student interest in systems engineering careers generally; systems engineering careers in government; and systems engineering careers in industry. A comparison was made between the means of the baseline survey respondents and post-survey matched group in all three categories. Results indicated that the matched group was biased toward systems engineering careers from the beginning, with higher mean scores on the baseline survey than the larger group of respondents. Post-survey means for the entire population of matched pre/post-survey responses decreased in all three categories, although these decreases were not statistically significant and none of the means were less than "3," indicating a moderate interest in systems engineering careers. Further analyses of students' responses show more subtle differences in the level of interest (from low to high) among the various subgroups analyzed. Where there was change was in the mean scores for those who chose 1, 2, or 3 on the 5-point scale in the baseline survey. This change was statistically significant in the direction of increased student interest in becoming a systems engineer for government.

An important component of the capstone experience was the inclusion of mentors who played multiple roles as technical experts guiding student teams toward solutions and risk assessment; as reviewers at interim and final design presentations; as clients who helped determine requirements; and as career advisors. PIs reported participation of over forty mentors from Department of Defense offices and other leading defense industry corporations (a full list is included in Appendix B of the report). All institutions that implemented capstone courses had DoD-assigned mentors in place before the start of the school semester, with the exception of two partner schools that did not have assignments, and one lead institution that utilized an advisory board of industry professionals. Similar to DoD-assigned mentors, industry mentors worked with students in all schools, excluding the two aforementioned partner schools, on specific problem areas (e.g., assistive or immersive training technologies, systems assurance, among others). Both DoD and industry mentors visited students on campus periodically, attended design reviews, and communicated with teams through email, phone, and video and teleconference.

Three-quarters of mentor survey respondents gave student projects high rankings for meeting their goals. Mentors reported wanting both formal and informal opportunities to communicate with students; however, scheduling conflicts were cited as the primary barrier to increased engagement. Almost 90% of surveyed students felt that mentor feedback had helped them with their projects. Students recommended that mentors interact with teams earlier in the semester; guide teams towards inquiry-based solutions; and set realistic expectations for projects. Beneficial impacts of mentor involvement were reported by PIs when communication was frequent, specific, and initiated early in the semester. Three-quarters of PIs interviewed in the final survey described mentorships as highly successful and efficient; in one instance, the intervention of a mentor was critical to a partnership, providing much needed clarification and encouragement for a student team that struggled to understand its role in providing systems assurance for another school located several time zones away.

Through site visits to systems engineering capstone universities in spring 2011, a team of sponsor representatives had identified nine promising practices—approaches that were present at universities where students demonstrated higher levels of communication, analysis, and awareness of the systems engineering process during the site visits. This year, all institutions incorporated three or more of the practices into their capstone courses. A graphical representation of the presence (or lack thereof) of these promising practices among all participating RT-19A universities appears in Table 32. The formation of cross-disciplinary teams, regular involvement with mentors, and attendance by mentors at student design reviews were practices adopted by nearly all of the participating schools. The recommendation to organize the fall lecture-based course, and to commence prototype design in the spring, was not implemented. PIs reported that they worked on DoD problem areas and simultaneously delivered engineering instruction in order to accommodate the academic calendar and also to coordinate research, materials, and personnel.

Another defining characteristic of the RT-19A capstone experience was scaling up to include five partnerships between a total of eleven schools. The report describes in detail capstone partnerships conducted over distance between service academies, civilian schools, and schools with and without systems engineering programs. The five partnership models were each qualitatively different, with models organized around the co-development of prototypes between teams or the delegation of one part of the systems engineering process to a remotely based team. Another type of partnership dealt exclusively with faculty professional development at two schools and had no direct student team collaboration. The coordination of communication among students in different engineering disciplines and geographical locations was one issue that impacted many of the partnerships that were geographically and temporally distant. Timely funding to support resource and capacity; existing faculty relationships between partnering schools; understanding of differences in school culture; consistent communication between partnering faculty members; complementary knowledge/skills and complementary research interests to ensure that all areas of expertise are covered within the collaboration; and student interest in DoD problem areas all contributed to successful partnerships. PIs reported that partner schools benefited from initial “meet and greet” sessions with students, mentors, and faculty to promote the collaboration; however, such relationships had to be continually encouraged and maintained.

Findings and Recommendations:

Limitations in the data and the many approaches and variables used in the 15 capstone courses prevent statistical correlations with student outcomes and “optimal” course designs. However, the following summary of findings are grounded in data collected through RT-19A:

Students enjoyed the real-world nature of the projects—both in terms of building an artifact that might be used and in terms of the systems engineering project context (budget constraints, interdisciplinary teams, experts as mentors)—and that they appreciated the contribution that the systems engineering perspective brought to their work. Mentorships and partnerships were an integral part of this year’s effort, and required management by faculty to coordinate communication and increase student content knowledge of systems engineering concepts.

Systems engineering capstone courses do not appear to have had a major impact on the students’ immediate career plans, although it must be noted that many had their immediate post-college plans in place and that a large majority of both undergraduates and graduate students believed that they might choose careers in systems engineering sometime in the future. Although significant planning toward logistics management, funding, personnel, curriculum design, and other major decisions is required prior to capstone course implementation, the majority of stakeholders in the research study (students, faculty/PIs, and mentors) reported benefits that ranged from increasing students’ exposure to the systems engineering process through the investigation of real-life problem areas; interaction with mentors from a variety of industries; and the facilitation of prototype design in multidisciplinary teams and remote collaborations.

Benefits of these school partnerships include:

- Schools that do not have systems engineering gain access to schools with systems engineering expertise
- Students at schools with only one engineering major are able to work in multidisciplinary teams
- Students have access to a wider variety of student skills and abilities when forming teams
- Students are exposed to a wider diversity of teammates
- Students are exposed to a wider variety of mentors

- Students at civilian schools gain access to military commands and to DoD problem areas
- Students learn the benefits and difficulties of working at a distance

New challenges introduced by these partnerships include:

- Students at different schools may have different academic calendars, be in different time zones, and therefore have difficulty coordinating schedules, meetings, delivery timelines, etc.
- Students may have difficulty communicating at a distance
- Students who cannot meet face-to-face may have difficulty learning trust, determining roles, and developing collaborations

The report concludes with some suggestions for how these partnerships might be facilitated on a national scale in the future.

1.0 INTRODUCTION

1.1 PROJECT OVERVIEW

A 45% growth is expected in systems engineering jobs in the next decade, and there have been numerous studies and workshops that have highlighted the shortfalls in both the number and capability of the systems engineering workforce (Rosato, Braverman, & Jeffries, 2009). The July 2006 National Defense Industrial Association (NDIA) Task Force noted among the top five systems engineering issues the lack of adequate, qualified systems engineering human capital resources within government and industry for allocation on major programs (National Defense Industrial Association SE Division Task Group , 2006). In the July 2010 NDIA white paper on critical systems engineering challenges, Issue 2 was identified as: *The quantity and quality of systems engineering expertise is insufficient to meet the demands of the government and defense industry*, and further outlined certain recommendations to build systems engineering expertise and capacity. In particular, it recommended developing systems engineering expertise through “role definition, selection, training, career incentives, and broadening ‘systems thinking’ into other disciplines,” and made a number of specific recommendations, including adding an introductory course in systems engineering in all undergraduate engineering and technical management degree programs; and working with major universities to recommend systems engineering curricula to improve consistency across programs in order to achieve standardization of skill sets for graduates (National Defense Industrial Association SE Division, 2010). With these industry-wide workforce demands challenging the systems engineering community, *Research on Building Education & Workforce Capacity in Systems Engineering* (referred to as the Systems Engineering Capstone Project) was conceptualized and designed to pilot and evaluate approaches to ameliorating these shortages in a select number of systems engineering institutions. The first year of the project, referred to as RT-19, took place in 2010-2011, resulting in a report dated October 31, 2011. This current report discusses the results of the second year, referred to as RT-19A, whose aim was to test the replication, scale-up and institutionalization of practices, instructional strategies, and course materials/resources judged effective during the first year. RT-19A also introduced the concept of partner schools, which were non-systems engineering schools that would partner with RT-19 schools in order to extend the reach and impact of the systems engineering effort. The results of both RT-19 and RT-19A are to inform the development of a national scale-up effort that will substantially expand the number and capabilities of universities that can produce the systems engineering graduates needed for the DoD and related defense industry workforce.

1.2 PARTICIPANTS AND RESEARCH SETTING

As was the case for RT-19, a request for proposals was issued and a competitive application process was conducted in order to select returning RT-19 institutions, both those that were Systems Engineering Research Center (SERC) members and the service academies, with proposals that included partnership opportunities receiving priority.

Altogether, 16 schools were selected to participate in the RT-19A effort: six SERC member universities, four service academies, and six partner schools. In comparison, 14 schools participated in RT-19, with ten of those schools returning for RT-19A.

RT-19A Lead School	Partner School
Air Force Academy	
Auburn University	Tuskegee University
Coast Guard Academy	Connecticut College
	University of Rhode Island
Missouri University of Science and Technology	
Military Academy	
Naval Academy	Smith College
Naval Postgraduate School	
Southern Methodist University	University of Hawaii at Manoa
Stevens Institute of Technology	
University of Virginia	Sweet Briar College

Table 1: Lead Institutions with Partner Schools

Research was conducted in the context of capstone systems engineering courses ("capstone courses") developed at 15 of the 16 schools. Tuskegee University did not develop a capstone course on its campus; instead, two faculty members acted as observing partners for the capstone course offered through Auburn.

In most cases, capstone courses were integrative, culminating, project-based experiences where teams of students worked together to develop a product or prototype that addressed a DoD need, such as low-cost, low-power computing devices; pre-positioned expeditionary assistance kits; expeditionary housing systems; immersive training technologies; and assistive technologies for wounded warriors. The goal was to embed, infuse, and augment systems engineering knowledge for undergraduate and graduate students, as defined by the Systems Planning, Research Development, and Engineering (SPRDE)-SE and Program Systems Engineer (PSE) competency model, known as the SPRDE-SE/PSE Competency Model (Table 2).

As was the case with RT-19, one of the goals of RT-19A was to examine student learning outcomes resulting from systems engineering capstone experiences. The Systems Planning, Research Development, and Engineering Systems Engineering and Program Systems Engineer (SPRDE-SE/PSE) competency model served as the standard for systems engineering knowledge and skill (see Table 2). Analysis of survey results from primary investigators, students, and mentors; input from site visits by the DoD DR&E sponsor; interviews with lead schools and their partners; and insights gleaned from panels and presentations at the culminating RT-19A workshop provide the data on which this final report and recommendations are based.

SPRDE-SE /PSE Competencies	
Analytical (13)	1. Technical Basis for Cost
	2. Modeling and Simulation
	3. Safety Assurance
	4. Stakeholder Requirements Definition (Requirements Development)
	5. Requirements Analysis (Logical Analysis)
	6. Architectural Design (Design Solution)
	7. Implementation
	8. Integration
	9. Verification
	10. Validation
	11. Transition
	12. System Assurance
	13. Reliability, Availability, and Maintainability
Technical Management (12)	14. Decision Analysis
	15. Technical Planning
	16. Technical Assessment
	17. Configuration Management
	18. Requirements Management
	19. Risk Management
	20. Technical Data Management
	21. Interface Management
	22. Software Engineering
	23. Acquisition
	24. Systems Engineering Leadership
	25. System of Systems
Professional (4)	26. Communications
	27. Problem Solving
	28. Strategic Thinking
	29. Professional Ethics

Table 2: SPRDE-SE/PSE Competencies Addressed in RT-19A

The universities that offered capstone courses were required to address one or more of five DoD problem areas and to produce an actual product, prototype, or other artifact to demonstrate their learning. Below is a list of the problem areas for RT-19A. These were identical to the problem areas for RT-19 but with the addition of a problem area referring to assistive technologies.

DoD Problem Areas

1. Low-cost, low-power computers leveraging open-source technologies and advanced security to support sustainable, secure collaboration;
   Portable, renewable power generation, storage, and distribution to support sustained operations in austere environments and reduce dependency on carbon-based energy sources; Portable, low-power water purification;
2. An expeditionary assistance kit around low-cost, efficient, and sustainable prototypes such as solar cookers, small and transportable shelters, deployable information and communication technologies, water purifiers, and renewable energies. These materials would be packaged in mission-specific HA/DR kits for partner nation use;
3. Develop modular, scalable, expeditionary housing systems that possess "green" electric power and water generation, waste and wastewater disposal, hygiene, and food service capabilities. Systems should be designed to blend in to natural/native surroundings and with minimal footprint;
4. Continued investigation and exploration into the realm of the possible with respect to "Immersive" training technologies. Objective is to flood the training audience environment with the same STIMULI that one would experience during actual mission execution. Where possible full sensory overload is desired much the same as experienced in combat. Specific S&T areas for development

   Virtual Human. Successful modeling of emotions, speech patterns, cultural behaviors, dialogue and gestures.

   Universal Language Model. The ability for trainees to seamlessly converse with the Virtual Human.

   Virtual Character Grab Controls. The ability for exercise controllers to assume control of virtual characters.

   Automated Programming. Cognitive learning models and the ability for exercise controllers to adjust virtual/live simulations.

   Low Cost wireless personnel sensors.

   Sensors (i.e., lightweight vests) that facilitate physical stimuli (i.e., wounds, shots) to trainees.
5. Assistive technologies for wounded warriors, including but not limited to application of haptic research, augmented reality, research on traumatic brain injury, bio-medical advances, hybrid assistive approaches (e.g., human- machine interfaces) and other leading- edge technologies to facilitate rehabilitation and contribute positively to wounded warrior quality of life.

Table 3: DoD Problem Areas

Systems Engineering Capstone RT 19 Promising Practices
1. Fall semester tools/techniques/approaches systems engineering theory course, followed by spring semester design project course. Fall course should present balance of "traditional" systems engineering approaches with automated tools/ models/ simulation techniques. 2. Creative imposition of technical, budget, and schedule constraints by faculty to model "real world." 3. Use of Systems Engineering doctoral students as project advisors. 4. Cross-disciplinary student teams. 5. Regular, direct involvement of mentors with student project teams-- e.g., significant meetings twice monthly with "on-call" consultations between meetings. 6. Creative use of mentors from defense prime contractors. 7. Structured design reviews with DoD and industry mentors serving as reviewers. 8. Civilian schools to establish relationships with nearby DoD commands and facilities. 9. For civilian institutions that have on-campus ROTC units, established relationships with ROTC units for requirements analysis, use case testing, and solution viability.

Table 4: RT 19 Promising Practices

In addition, the participating PIs were asked to incorporate as many of the nine Promising Practices identified in the previous year as feasible in their courses. These are listed in Table 4.

Finally, as noted above, the goal of increasing the number of schools offering systems engineering capstone courses was approached by developing partnerships between RT-19 participants and non-systems engineering schools. As a result, three civilian schools (Auburn, Southern Methodist University, and University of Virginia) and two service academies (Coast Guard Academy and Naval Academy) from RT-19 created partnerships with six new schools (Connecticut College, Smith College, Sweet Briar, Tuskegee University, University of Hawaii Manoa, and University of Rhode Island). This effort will be discussed in more detail below.

1.3 RESEARCH QUESTIONS AND METHODS

The key research questions this program was designed to address are:

(1) What are institutional challenges and successes in the adoption of core elements of successful systems engineering capstone projects?
(2) What are the contexts and program characteristics leading to highly successful student team-developed products and artifacts that respond to authentic Department of Defense (DoD) problem areas?

Each RT-19A lead school and some partner schools administered two types of assessment to their students:

- Customized pre-/post assessments that were targeted to their own course learning objectives. Assessments were typically developed by the course instructors and related to specific course content, ranging from multiple choice response tests, to a performance-based assessment, to other types of authentic assessments.

- A common student assessment developed by the research team and administered in survey format at the beginning and end of the academic year that:
    - Gauged changes in student involvement in, and understanding of, the systems engineering design process, including requirements analysis, project management, and testing phases; system level trade-offs; and the nature and type of client and mentor interactions
    - Gauged changes in student interest in systems engineering study and systems engineering careers, including DoD systems engineering careers
    - Collected demographics, including gender, race/ethnicity, major, class year and status, prior experience with systems engineering, etc. from participating students

In addition, faculty at each participating institution developed customized assessments that were unique to their courses using diverse instruments such as competency rubrics, student presentations for design reviews, peer reviews, and team reports.

In addition to analyzing the results of the student- and faculty-level assessments and surveys, the following report includes case studies of partnerships, describing the best practices, models, approaches, and conditions, as well as the ineffective practices and unresolved challenges.

1.4 TIMELINE

The program was implemented in three sequential phases over an 18-month period:

During Phase 1/Planning and Startup (April 1, 2011-June 30, 2011), the research team, with participation from the sponsor agency, developed the requirements and specifications, timeline, and funding limits for the systems engineering capstone courses; developed the research design and project evaluation plan; developed and issued the request for proposals and selection process (through an independent review team and rubric) for selecting participating schools; and selected six systems engineering member schools and four service academies with systems engineering or general engineering programs that would participate in the project. As noted above, five of those schools (hereafter “lead schools”) recruited six non-systems engineering partner schools.

During Phase 2/Development and Implementation (July 1, 2011-June 30, 2012), participating schools that would offer capstone courses recruited student participants; developed and organized course materials; coordinated interactions between students, mentors, and clients; planned assessments; delivered systems engineering instruction to student teams; and participated in recommended student competitions and conferences (Spring 2012). As we will see below, lead schools with partners managed their capstone course and prototype development in different ways. Finally, PIs from all the participating schools submitted an interim and final survey that asked about the scaling process, the challenges to sustainability, and the reasons behind the success (or lack thereof) demonstrated by the student prototypes.

During Phase 3/Analysis, Recommendations & Dissemination (July 1, 2012 – September 30, 2012), the research team analyzed results from all participating schools and integrated them into a single set of findings about the effectiveness of the programs using a variety of metrics:

- Institutional infrastructure and institutionalization
- Effectiveness of course structure, materials, and external inputs (mentors and clients)
- Success of student projects
- Student learning of systems engineering skills and competencies
- Partnerships as a means of scaling up

2.0 THE CAPSTONE EXPERIENCE

This section of the report will look at the success of different aspects of the capstone experience. It is based on a series of surveys given to the three groups that participated in RT-19A: primary investigators (instructional, as well as supporting administrative or advisory faculty); undergraduate and graduate students who were enrolled in the capstone courses; and mentors (DoD and industry). Primary investigators (PIs) were asked to respond to an interim and final survey. Although 16 schools were involved in RT-19A, 13 PIs responded to the interim survey and 9 to the year-end survey. The three that did not respond to the interim survey were Tuskegee, University of Rhode Island, and Naval Postgraduate School, while the seven that did not respond to the year-end survey included five of the six partner schools along with the Air Force Academy and the Naval Postgraduate School. As noted above, Tuskegee University did not create a capstone course or enroll students but instead monitored Auburn's course so the survey did not apply to them, while the Air Force Academy had not finished by the time the final survey went out and the Naval Postgraduate School operated on an entirely different schedule from the other institutions. The only partner school PI who answered the final survey was from the University of Hawaii-Manoa, one of the more successful partnerships (see below).

Students were asked to respond to a baseline survey administered in September 2011 and year-end survey administered in May 2012. The response differed by institution, with more complete data presented in the appropriate section. Mentors were asked to respond to a survey sent them in May 2012.

2.1 CAPSTONE COURSE ORGANIZATION

One of the recommended promising practices was to implement the capstone course over two semesters, with the first semester focusing on theory and the second on design. With the exception of Tuskegee, all of the RT-19A schools implemented the systems engineering capstone course experience over two semesters. However, only the Naval Academy adopted the practice of having formal lectures on systems engineering theory during the fall semester and confining prototype design to the spring semester, although even here, the students designed paper prototypes in the fall. Most of the other schools reported that students worked on a combination of theory-related lecture and prototype development or systems testing during the fall, although at University of Virginia students did not receive formal lectures but learned systems engineering concepts in a "just-in-time" manner as they developed their prototypes. The nine-month academic calendar, delays in materials acquisition, technical problems with components or prototypes, and other issues were cited by the remaining PIs as reasons for beginning the design process as early as possible.

One promising practice was to have PIs impose technical, budget, and schedule constraints on the students' projects in order to model the real world. All the PIs reported that they had done this, and in fact it was built into the semester structure and each school's existing budget constraints.

The extent to which students developed prototypes varied from school to school (see Table 5). At three schools (Coast Guard Academy, Naval Academy, Southern Methodist University), the goal of the capstone courses was to develop functional physical prototypes. At Stevens, the PI noted that the prior year's prototypes had been conceptual in nature, this year the students had focused on "data acquisition and model validation." Similarly, students in Missouri University of Science and Technology's Physical Artifact capstone course worked on validating the designs created by capstone students in RT-19. Student teams at three schools worked on development of two or more different prototypes. At Smith College and University of Hawaii Manoa, students worked on subsystems for their partner schools.

School	**Prototype**
Air Force Academy	A. Small scale, low voltage, battery management and charging system B. Small scale model of the power plant and vehicle providing proof of concept
Auburn	Lightweight, portable unmanned aerial vehicle (UAV) launched by a soldier to reconnoiter a hostile environment. Teams built a rotary wing UAV and "lighter than air" UAV
Coast Guard Academy	A. Shipboard wastewater treatment system development for Coast Guard cutters (includes development of membrane-bioreactor for treating shipboard gray water and pollutant removal) B. Natural gas engine conversion C. Autonomous sailing vessels
Connecticut College	Small sailing robots that can operate autonomously in navigation and communicate with each other for coordinated operations
Military Academy	Cockpit/Crew Station of the Future (2035) used as a simulator to train pilots.
Missouri University of Science and Technology	Immersive training vests with position reporting and vibrators
Naval Academy	Fully functional, independently powered (e.g. renewable power source) water purification system capable of supporting at least 80 people from multiple water sources
Smith College	Water purification system – specifically, power sub-system in partnership with Naval Academy
Southern Methodist University	Interactive, immersive training environment with human gesture tracking and facial emotion capture

Stevens	Prepositioned Expeditionary Assistance Kit/Green Housing - Shelter, grey water recycling system, tied into on-campus mechanical tri-generation systems, alternative energy (wind belt) and overall simulator
Sweet Briar	Immersive technology to alleviate phantom limb pain
University of Hawaii	Distributed systems assurance processes and methods in partnership with Southern Methodist University
University of Virginia	Rapid Adaptive Needs Assessment (water sampling) kit of physical sensors and communications equipment in waterproof container with anchoring systems Virtual environment, hardware to sense location and grip of user's hand, and structure designed to project virtual environment onto a tabletop

Table 5: Types of Prototypes Developed in RT-19A

2.2 SYSTEMS ENGINEERING COMPETENCIES AND DEFINITIONS

The SPRDE-SE/PSE Competency Model guided faculty design of course foci over the two semester long capstone experience. Competencies that were most frequently listed as course foci included Problem Solving (84.6%), Stakeholder Requirements Definition (69.2%), Requirements Analysis (69.2%), Verification (69.2%), and Communication (61.5%). The competencies among the most infrequently reported as course foci were Technical Assessment, Configuration, and Acquisition.

PIs were split between those who presented students with formal definitions of systems engineering and those who preferred more experiential interpretations. Auburn, Stevens, Air Force Academy, University of Virginia, and Naval Academy all reported using the definition of systems engineering from the International Council of Systems Engineering (INCOSE) to help students clarify the main concepts and relations of a complex discipline:

> Systems engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, and then proceeding with design synthesis and system validation while considering the complete problem: operations, cost and schedule, performance, training and support, test, manufacturing, and disposal. Systems engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs.

At Southern Methodist University, the PI reported that students benefited from first learning practical design skills ("interface management, iterative systems development, integration, etc.") before combining those skills into a theoretical understanding of systems engineering:

> Based on RT-19 experiences, we only confused students by introducing the general and abstract systems engineering concepts that early. Thus in Fall 2011 Senior Design I, we educated students on the skill set of systems engineering including how to perform iterative system development, system integration and interface management, risk identification and management. In addition, students learned, understood and applied the above skills along with the project design and prototyping. Then in Spring 2012, we will arrange a joint systems engineering lecture to define systems engineering and discuss why we need systems engineering, etc.

Finally, other PIs defined systems engineering for their students more informally, stressing the "big picture of systems"; the role of the "multi- or inter-disciplinarity of engineering disciplines" in the development and maintenance of systems; "project management"; and the need for "designing optimal solutions for the client while analyzing risk."

2.3 FACULTY INVOLVEMENT

Fifty-one faculty members participated in the development, delivery, or assessment of RT-19A courses, almost the same number as participated in RT-19 (50). This year's faculty came from Industrial, Electrical, Civil, Mechanical, Systems, Software, Ocean Engineering, and Computer Science. The highest percentage came from Mechanical Engineering, followed by Systems Engineering. Eight schools included faculty participants from more than one engineering discipline.

Figure 1 shows the percentages of all faculty members in the project:

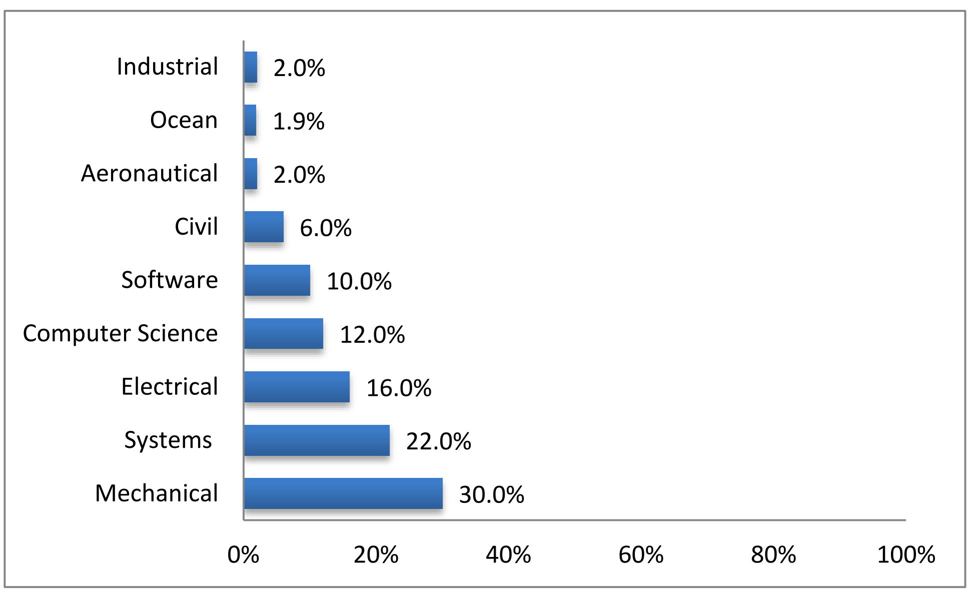

Figure 1: RT-19A Participating Faculty by Discipline

2.4 GRADUATE STUDENT INVOLVEMENT

Another RT-19 Promising Practice was to have Systems Engineering doctoral students act as project advisors to students enrolled in the capstone courses. This was a much more prevalent practice this year than last year, with eleven graduate students at seven different institutions acting as project managers, teaching assistants, and/or mentors to RT-19A teams. These students helped teams manage risk, balance workload across team members, and coordinate deliverables and project artifacts in a timely manner. Thus at Southern Methodist University the student teaching assistant monitored students' progress through weekly project status reports and surveys. Systems engineering doctoral students at Missouri University of Science and Technology facilitated weekly WebEx meetings between capstone students, the faculty advisor, and industry mentors. The graduate student project manager at Stevens was a previous participant in the RT-19 effort who served as a knowledge resource for the RT-19A teams working on a new iteration of the previous year's problem area. At Auburn, the graduate student assistant worked to ensure that systems engineering concepts were employed and that outside help was sought when appropriate. Finally, at Air Force Academy and University of Virginia, graduate students acted as occasional mentors who responded to technical inquiries.

2.5 STUDENT RECRUITMENT

Faculty employed multiple strategies to recruit students to the capstone courses, with most considering face-to-face recruitment to be the most effective strategy.

At Stevens and Auburn, word of mouth from students in the previous year had the greatest impact on recruitment. PIs at University of Virginia reported that conversations with faculty from other departments were helpful while PIs at Southern Methodist University said that they had help from senior design faculty. The graph below shows the methods most frequently used, with most schools using more than one:

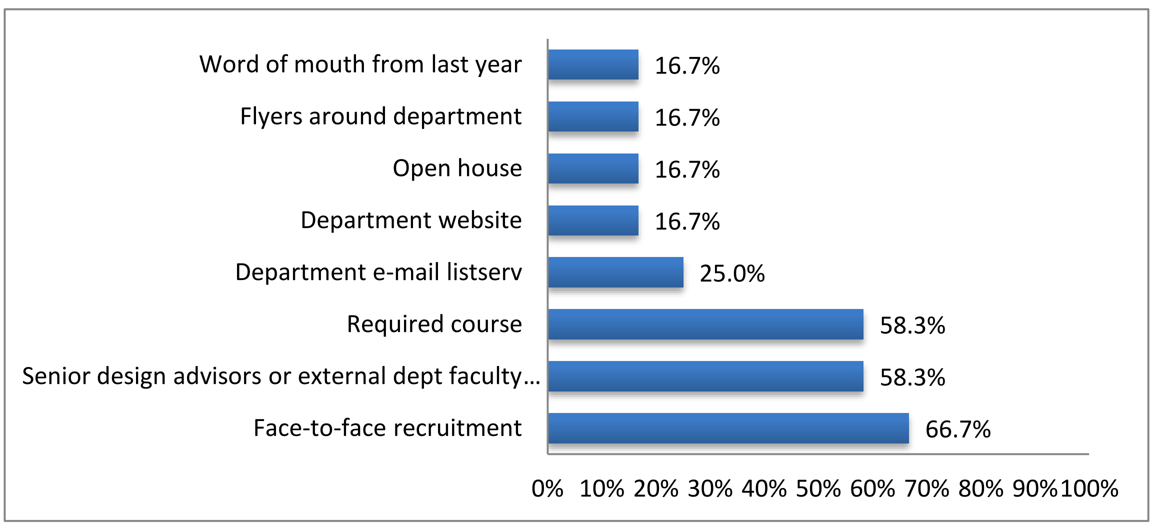

Figure 2: Methods of Recruiting Students

2.6 DOD PROBLEM AREAS ADDRESSED

Each of the universities, including lead and partner schools, chose one or more of five DoD problem areas. Three schools addressed multiple problem areas. Problem areas 2 and 4 were the most frequently chosen, while problem areas 3 and 5 were least represented. Figure 3 shows the percentage of schools choosing each area, while Table 6 shows the problem areas addressed at each school.

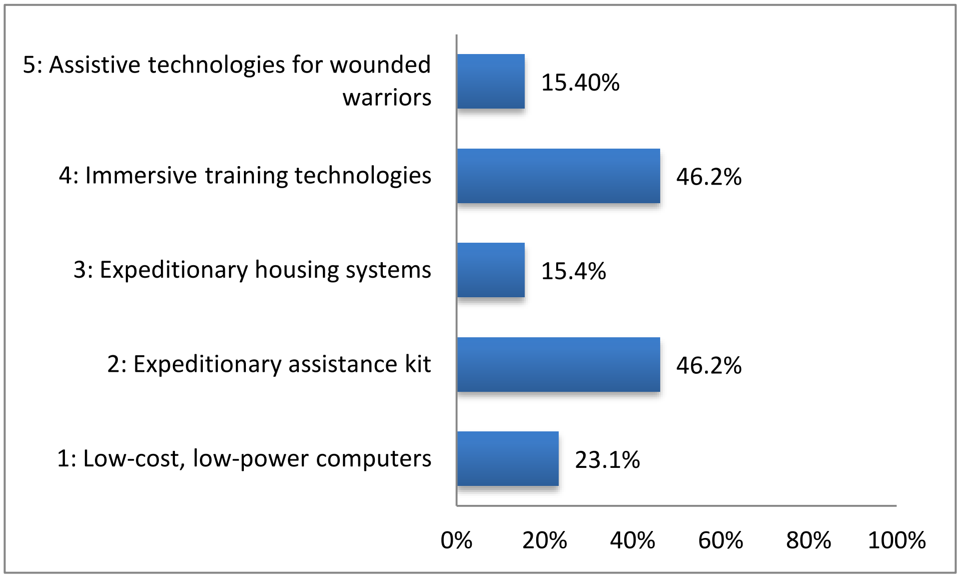

Figure 3: DoD Problem Areas Addressed

RT-19A School	Problem Area
Air Force Academy	2
Auburn	1
Coast Guard Academy	1,2,3
Connecticut College	1,2
Military Academy	4
Missouri University of Science and Technology	4
Naval Academy	2
Smith College	2
Southern Methodist University	4
Stevens	3

Sweet Briar	4,5
University of Hawaii	4
University of Virginia	2,4,5

Table 6: Problem Areas by School

The PIs listed student interest, faculty interest, and faculty subject matter expertise as the most important reasons for selecting a problem area. At several schools (Missouri University of Science and Technology, Stevens, Southern Methodist University, and University of Virginia), students worked on problem areas carried over from the previous year. Two schools reported that they selected the problem area based on client needs (Military Academy, Southern Methodist University). At two partner schools (Connecticut College, University of Hawaii Manoa), the lead school decided on the problem area. Figure 5 shows the percentage of PIs who listed each reason.

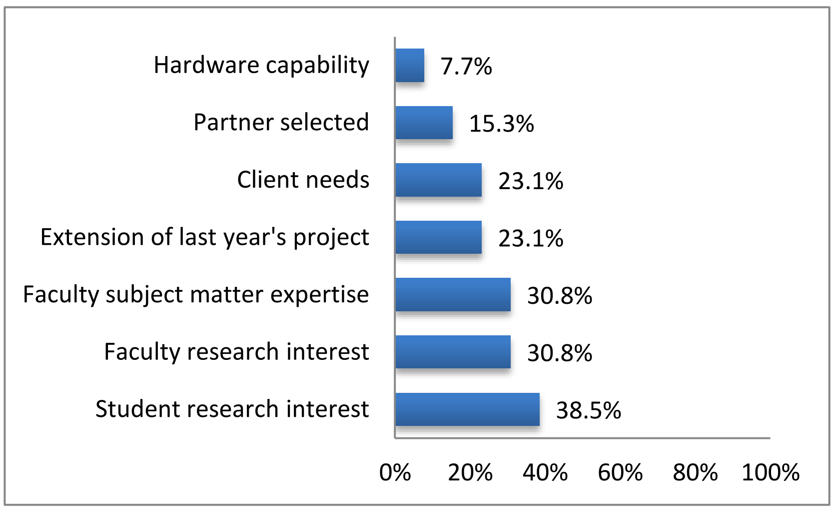

Figure 4: PI Reasons for Selecting Problem Areas

2.7 ROTC PARTICIPATION AND RELATIONSHIPS WITH NEARBY DOD FACILITIES

Two other recommendations from RT-19 were that schools collaborate with on-site or nearby ROTC units for "requirements analysis, use case testing, and solution viability" and that civilian schools establish relationships with nearby DoD commands or facilities. Only two schools reported that they had an existing ROTC unit. At the Naval Academy, the PI interpreted the definition of ROTC broadly and called the entire school "essentially an on-campus ROTC unit." Auburn facilitated such a relationship by using a sergeant in the local Army ROTC unit with UAV deployment experience "to validate the description of the functional requirements" of the student prototype during the spring semester. As for establishing relationships with nearby command facilities, two civilian schools (Smith and Connecticut College) established such relationships by partnering with military schools, but none of the other civilian schools established new relationships.

3.0 STUDENT PARTICIPATION

3.1 STUDENT PARTICIPATION IN CAPSTONE COURSES

A total of fifteen schools in RT-19A enrolled students in a systems engineering capstone course, compared to fourteen schools in RT-19. Figure 5, using data from the interim faculty surveys, compares the participation rate in RT-19 with that for RT-19A. It should be noted that the total for the spring semester was a prediction made before the semester began. It was larger than the total for the fall semester primarily because of increased participation at two of the service academies (Coast Guard Academy and Naval Academy).

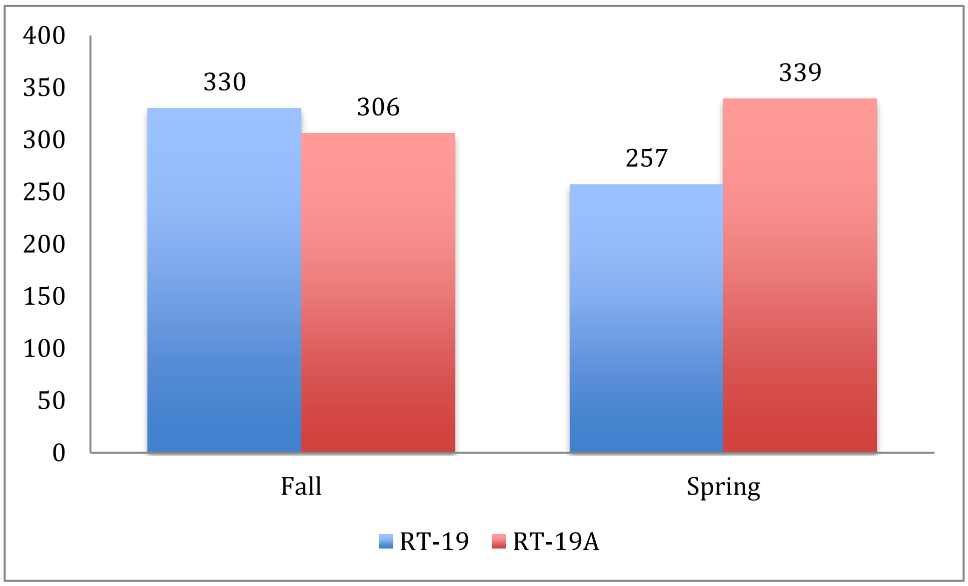

Figure 5: Student Participation, Fall and Spring Semesters, RT-19 and RT-19A Compared

However, the number of students who enrolled in the capstone courses was higher than the number of students who worked specifically on DoD problem areas. Thus the PIs reported that 198 students were expected to work on DoD problem areas during the spring semester, or 64.7% of the total number of students enrolled in the course.

The PIs reported that team sizes ranged from 2 -15, with teams of three, four, and five students most frequent. However, there was a great deal of variety in team size and number of teams at each school. For example, the Naval Academy had two of the largest teams, with 13 and 15 students on each, while the Coast Guard Academy had the greatest number of teams (10) but these had only four students per team.

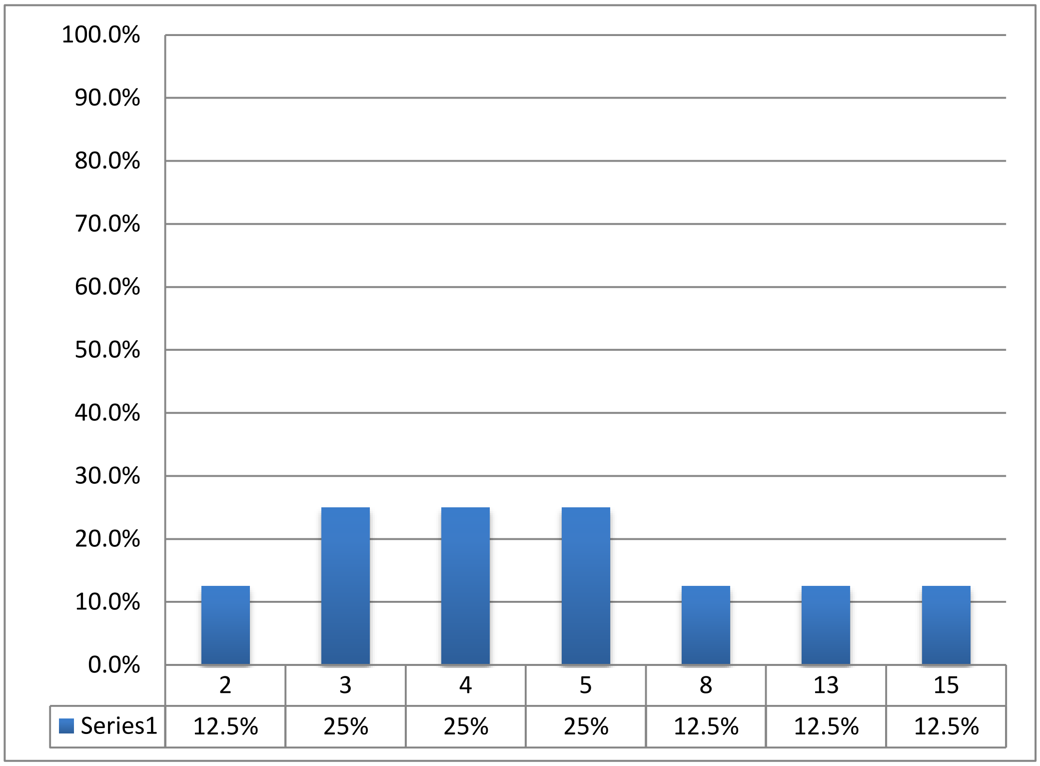

Figure 6: Team Size

3.2 DEMOGRAPHICS OF STUDENT PARTICIPANTS

This section will provide an overview of the demographic characteristics of the students engaged in the RT-19A capstone courses. It is based on an analysis of student background surveys, which were received from 12 of the 16 participating schools with students. In Table 7 those schools with no student responses are highlighted in gray. As noted above, Connecticut College and University of Rhode Island joined their projects late, while Tuskegee had no students and Naval Postgraduate School is not included because it was on a different schedule from the other participating schools.

RT-19A Lead School	**Partner School**
Air Force Academy	
Auburn	Tuskegee University
Coast Guard Academy	Connecticut College
	University of Rhode Island

Missouri University of Science & Technology	
Military Academy	
Naval Academy	Smith College
Naval Postgraduate School	
Southern Methodist University	University of Hawaii Manoa
Stevens	
University of Virginia	Sweet Briar

Table 7: Schools with Students Submitting Background Surveys

A total of 196 students returned the baseline survey, or 68% of the number of students reported by the PIs to have been enrolled in the fall semester capstone course. Table 8 shows the number of baseline surveys returned from each school.

	Baseline surveys
Air Force Academy	31
Auburn	31
Coast Guard Academy	26
Military Academy	4
Missouri University of Science and Technology	19
Naval Academy	28
Smith College	4
Southern Methodist University	8
Stevens	20
Sweet Briar	4
University of Hawaii	4
University of Virginia	17
Total	196

Table 8: Baseline Survey Responses

Based on these responses, the following sections will discuss:

- Survey participation rate
- Academic status and class year
- Major

- Gender and Ethnicity
- Experience with general engineering
- Experience with systems engineering
- Systems engineering career interest

Comparisons between RT-19 and RT-19A will be made where relevant. Because the demographic student data is based on a subset of all the participants, any generalizing from the results must be done with caution.

3.3 ACADEMIC STATUS AND CLASS YEAR

It appears from the survey responses that RT-19A involved more undergraduates and far fewer graduate students (as students, not mentors) than RT-19 (see Figure 7).

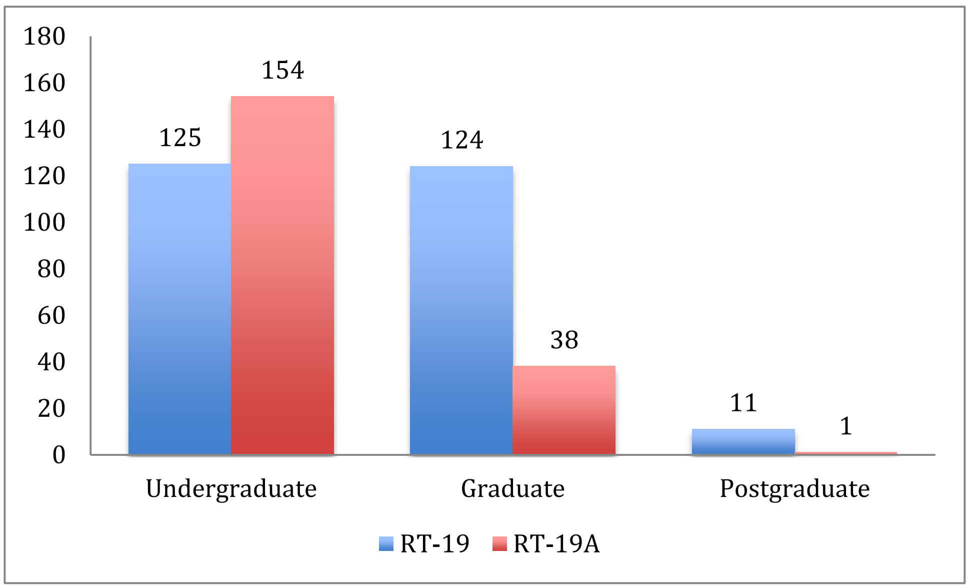

Figure 7: Number of Undergraduate and Graduate Students in RT-19 and RT-19A

In addition, while for RT-19, several schools had a mixture of undergraduates and graduates in a single class, for RT-19A, students from only one school (Auburn) reported a mix—in this case, a class of 31 that was two-thirds graduate students and one-third undergraduates. Missouri Institute of Science and Technology had entirely graduate students while all the others had entirely undergraduates.

Most of the undergraduate respondents were seniors, while most of the graduate students were in their first or second year of graduate school. Tables 9 and 10 show class status for all respondents and by individual school.

	Frequency	Percent
First year graduate student	19	9.7
Second year graduate student	15	7.7
Third through fifth year graduate student	8	4.1
Undergraduate Junior	1	0.5
Undergraduate Senior	150	76.5
No response	3	1.5
Total	196	100.0

Table 9: Survey Respondents by Class Year

	Class Status			Total
	Grad	Postgrad	Undergrad	
Air Force Academy	0	0	31	31
Auburn	21	0	10	31
Coast Guard Academy	0	0	26	26
Military Academy	0	0	4	4
Missouri University of Science and Technology	18	1	0	19
Naval Academy	0	0	28	28
Smith College	0	0	4	4
Southern Methodist University	0	0	8	8
Stevens	0	0	20	20
Sweet Briar	0	0	4	4
University of Hawaii	0	0	4	4
University of Virginia	0	0	17	17
Total	39	1	156	196

Table 10: Survey Respondents by School

3.4 STUDENT MAJORS

The most common major overall was Systems Engineering, followed by Mechanical and Electrical Engineering (see Figure 8). About 30% of those returning surveys were Systems Engineering majors, distributed among seven of the twelve schools. Students majoring in Mechanical Engineering were distributed across three schools while students majoring in Electrical Engineering were distributed across four schools. Majors represented by only one student included Accounting and Finance, Biomedical Engineering, Environmental Science, and Computer Science Engineering.

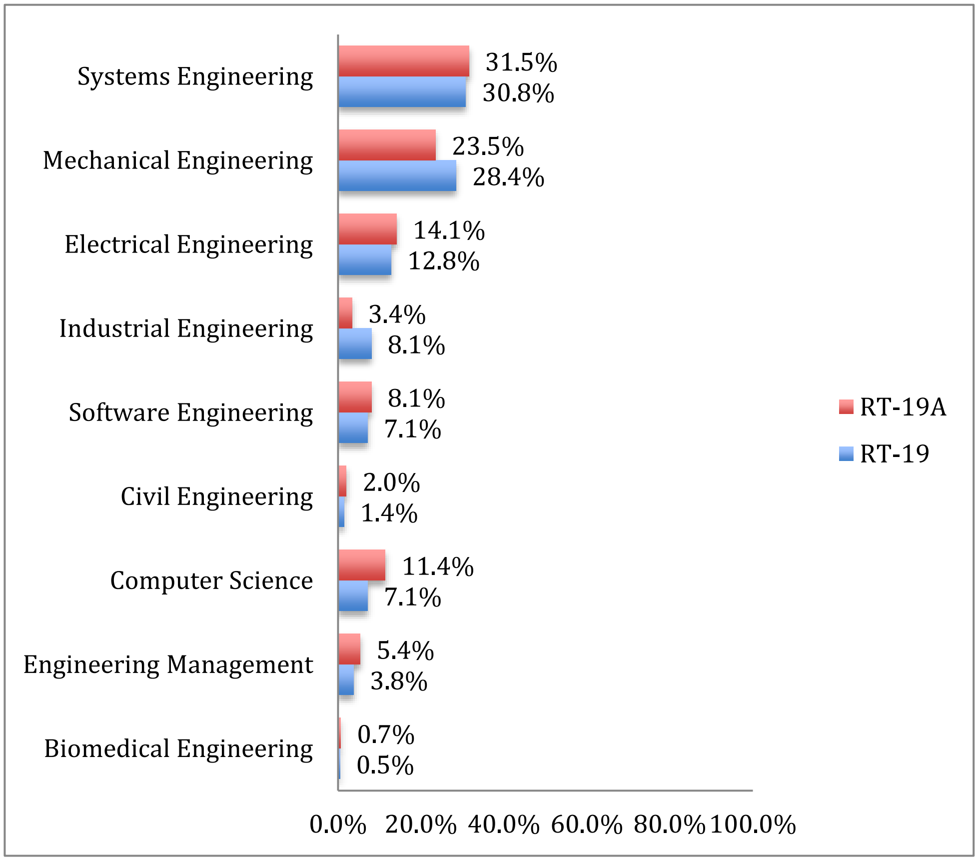

Figure 8: Student Majors, RT-19 and RT-19A Compared

Another recommendation from RT-19 was that students form cross-disciplinary teams. In RT-19A, students at nine of the schools that had students responding to the baseline survey came from two or more engineering disciplines, while students at three schools came from one engineering discipline. For two of these three (Smith College and Sweet Briar), this was the only major available. Over three-quarters of the students who answered “Other” described their major as General Engineering, while most of the rest were in non-engineering majors (see Table 11). Table 12 shows engineering majors by school.

General Engineering	20	77.0
Information Technology Management	3	11.6
Accounting and Finance	1	3.8
Environmental Science	1	3.8
Computer Science Engineering	1	3.8
Total	26	100.0

Table 11: "Other" Majors

School	**Disciplines**
Air Force Academy	Computer Engineering, Electrical Engineering, Engineering Management, Systems Engineering
Auburn	Systems Engineering, Mechanical Engineering, Electrical Engineering
Coast Guard Academy	Civil Engineering, Electrical Engineering, Mechanical Engineering
Military Academy	Systems Engineering
Missouri University of Science & Technology	Electrical Engineering, Computer Engineering, Mechanical Engineering, Industrial Engineering, Systems Engineering
Naval Academy	General Engineering, Systems Engineering (Multidisciplinary major)
Smith College	General Engineering
Southern Methodist University	Computer Science (software focus), Computer Engineering (hardware focus)
Stevens	Mechanical Engineering, Electrical Engineering, Civil Engineering, Engineering Management, Computer Engineering, Systems Engineering
Sweet Briar	General Engineering
University of Hawaii Manoa	MIS, Finance, Accounting, Management

University of Virginia	Systems Engineering, Engineering Management, Biomedical Engineering, Computer Engineering

Table 12: Engineering Majors by School

3.5 GENDER AND ETHNICITY

The student population that returned surveys was over three-quarters male, approximately the same as last year, and about 20% female compared to 17% last year. This increase was in part due to the participation of two women's college, Sweet Briar and Smith, but the overall balance is in line with engineering schools nationally.

Gender	RT-19A Frequency	RT-19A Percent	RT-19 Percent
Male	154	78.6	76.8
Female	40	20.4	17.4
No response	2	1.0	6.8
Total	196	100.0	100.0

Table 13: Gender, RT-19 and RT-19A Compared

The ethnicity of the responding students was only slightly different from the ethnicity reported last year. Over two-thirds (68%) of the students in RT-19A reported their ethnicity as White, slightly more than the 64% for RT-19. This was followed by Asian and African-American/black students, with the percentage of the latter slightly higher than the 6.8% last year.

Ethnicity	RT-19A Frequency	RT-19A Percent	RT-19 Percent
White	133	67.9	64.3
Asian	21	10.7	11.4
Black or African American	21	10.7	6.8
Hispanic/Latino	5	2.6	5.3
Native Hawaiian or Other Pacific Islander	2	1.0	0.01
American Indian/Alaska Native	3	1.5	0.01
No response	11	5.6	11.4
Total	196	100.0	100.0

Table 14: Ethnicity

3.6 PRIOR EXPERIENCE WITH ENGINEERING

All but 13 (6.6%) of the survey respondents reported having had prior engineering experience, either through full-time employment, an internship or co-op, summer work, or a combination of these. However, almost one-third did not respond to this question, presumably because they had no experience, so the percentage with no experience may have been closer to 40%. These percentages where almost the same as last year.

	Frequency	Percent
Some engineering experience	116	59.2
No engineering experience	13	6.6
No response	67	34.2
Total	196	100.0

Table 15: Prior Engineering Experience

A higher percentage of the responding students (49%) reported having no systems engineering experience this year compared to last year, when only 40% reported such experience. As can be seen in Table 16, the largest percentage of those who reported this type of experience had gained it through coursework (28.6%), followed by summer employment (10.7%).

	Frequency	Percent
System engineering experience	77	39.3
Not sure	17	8.7
No	96	49.0
No response	6	3.0
Total	196	100.0

Table 16: Prior Systems Engineering Experience

3.7 PRIOR EXPERIENCE WITH MULTIDISCIPLINARY TEAMS

As noted above, one promising practice was to have students work in multidisciplinary teams. This year, only about half (52%) of the students reported that they had prior experience working in multidisciplinary teams, generally in an engineering course or other academic context.

	Frequency	Percent
Yes, in an engineering course	88	44.9
Yes, in another course	14	7.1
Not sure	21	10.8
No	73	37.2
Total	196	100.0

Table 17: Prior Experience with Multidisciplinary Teams

4.0 FACULTY PERCEPTIONS OF RT-19A SUCCESSES AND CHALLENGES

4.1 PERCEPTIONS OF STUDENT ENGAGEMENT

When the PIs were asked what had engaged the students about their projects, they cited interest in real-world problem areas; "hands-on" design and teamwork opportunities; experience with the systems engineering process; and exposure to industry professionals. These were the same attractions reports last year. Here are some examples from the PI surveys:

> The real-world, tangible nature of the problem they were working on. 2. The ability to get lots of hands-on work building their system. 3. Excitement about being afforded the opportunity to complete a capstone project. 4. Having 2 teams at USNA working on the same problem. Led to a healthy sense of competition…The hands-on work on the projects was especially rewarding for the students. Seeing their ideas come to physical fruition and getting to test them was very rewarding. Conducting Integration, Verification, and Validation testing at each step as they progressed from small sub-system to overall working prototype really made the Systems Engineering process come to life for the students. (Naval Academy)

> Student development teams started understanding the role of their UH collaborative teams and tried to communicate with each other. One team well leveraged the UH system assurance team helped them to develop the risk management reports for their design review presentations and final design review. (Southern Methodist University)

> Driving factors for student engagement included that each team worked on a project in an area of relevance to their faculty advisor, that the teams were expected to build and test their design, and that the deliverables for the project were not so frequent and cumbersome as to detract from design and testing. (University of Virginia)

PIs at two schools cited student interest in designing prototypes and systems with applications in sustainable energy and humanitarian relief as important attractions:

> Students like things that MOVE, make noise, or make lights. The off-road vehicle appeals to the MOVE motivator but also appeals to the growing sense of a need for non-fossil fuel based vehicles. (Air Force Academy)

> Students have an intrinsic interest in projects that involve sustainability in engineering and the connection to disaster relief provides additional engagement. The industry mentors have further reinforced these themes through their direct experience. (Stevens)

This year, however, faculty also included interactions between students and mentors, faculty expertise carried over from last year's project, competition among teams, making full use of partner teams, and the prestigious nature of the DoD projects as important in engaging students. Table18 lists the aspects of student engagement cited by faculty at each school.

Communication with clients and mentors	Air Force Academy Coast Guard Academy Military Academy Missouri University of Science and Technology Southern Methodist University University of Virginia
Interest in real-life problem	Auburn Naval Academy Smith College Sweet Briar University of Virginia University of Hawaii Manoa
Grasp of systems engineering content knowledge	Air Force Academy Missouri University of Science & Technology Southern Methodist University Smith College University of Hawaii Manoa
Creation of a physical prototype - "hands-on" activity	Auburn Coast Guard Academy Naval Academy
Weekly debriefing and planning meetings between PIs and/or teaching assistants	Auburn Missouri University of Science & Technology University of Virginia
Faculty technical and teaching experience carried over from last year's project	Stevens University of Virginia
Collaboration between student teams (teams include capstone teams, internal university collaborations & partner schools)	Coast Guard Academy Southern Methodist University University of Virginia
Utilization of subject matter expertise	Sweet Briar University of Virginia University of Hawaii Manoa
Experiencing the systems engineering process from concept to testing	Naval Academy University of Virginia
Prestige of DoD projects	Southern Methodist University University of Hawaii Manoa
Competition against other teams	Military Academy Naval Academy
Work with a faculty member from another	University of Virginia

discipline	
Solicitation of RT-19A students	University of Hawaii Manoa
Student team organization	Naval Academy
Communication between PIs/ graduate student advisors to students	Military Academy
Assignment of Systems Engineering PhD students as project managers	Military Academy
Increased professional and academic networking opportunities	Connecticut College

Table 18: Aspects of Student Engagement by School

4.2 PERCEPTIONS OF CHALLENGES

The PIs reported a number of challenges, several of which were common to many schools and some of which were particular to only one or two. Many of these challenges were technical problems with physical prototypes, their components, and systems integration, although some were related to communication over distances.

In the interim survey, nearly half of the PIs reported that students struggled with systems engineering concepts and content knowledge. In the final survey, in contrast, PIs commented more on challenges relating to prototype construction, such as the difficulties students experienced in modifying off-the-shelf (COTS) software and hardware (e.g., Microsoft Kinect, batteries); difficulties with parts that did not meet manufacturer specifications (Auburn, Southern Methodist University, Naval Academy); difficulties with time management given student schedules and workload (Military Academy, Naval Academy); delays in parts acquisition (Military Academy); budget limits (Auburn); and having to rely on Internet blogs to solve certain technical problems (Auburn). Other concerns included the “open-ended nature of the problem distributed across a large number of students” (Stevens) and the lack of specific disciplinary expertise on teams (University of Virginia). At the Naval Academy, a school with large teams, the division of teams into sub-teams that worked well on the both initial design and the later testing process nevertheless led to unequal student workloads at different times in the semester. To combat this, the PI recommended that in the future students create “flexible teams, exchanging roles on sub-teams and moving into different sub-teams as needed.”

Table 19 lists the challenges reported by faculty at each school throughout the year.

Challenge	Schools
Systems Engineering concepts and content knowledge	Auburn Naval Academy Southern Methodist University Smith College Stevens University of Virginia
Communication between team members from separate engineering disciplines or partner schools	Auburn Smith College Sweet Briar University of Hawaii Manoa University of Virginia
Team diversity and composition	Auburn Naval Academy Sweet Briar
Space for large-scale prototype design or meetings	Coast Guard Academy Naval Academy University of Virginia
Modification of COTS hardware and software	Auburn Naval Academy Southern Methodist University
Time constraints	Coast Guard Academy Missouri University of Science & Technology Naval Academy
Parts acquisition – pricing, delays	Auburn Military Academy
Alignment of course materials/lectures with project design	Naval Academy Southern Methodist University
Restrictions on communication with government mentors or military schools	Smith College Southern Methodist University
Funding delays/subcontracting	Connecticut College University of Hawaii Manoa
Management of student workload	Military Academy Naval Academy
Communication between students & faculty on technical problems	University of Virginia
Communication between engineering departments	Military Academy

Alignment of grading across various courses and departments	Southern Methodist University
Open-ended problem solving	Stevens Institute
Lack of specific engineering disciplinary expertise on team	University of Virginia

Table 19: Challenges by School

As will be described in the section on partnerships, teams formed with partner schools encountered particular challenges and opportunities.

5.0 IMPACT OF RT-19A ON STUDENTS

5.1 DATA SET FOR ASSESSING IMPACT ON STUDENTS

Fewer students responded to the final post-course survey than had responded to the baseline (pre-course) survey (see Table 20). In addition, over half of the post-course survey respondents had not responded to the first survey and so their results could not be matched. In fact, there were far fewer matched pre- and post-course surveys, with the number depending on the question. In the discussion that follows, the entire set of post-survey responses will be analyzed for those questions where this is relevant while the matched response set will be used to look at change over time.

	Baseline surveys	Final surveys
Air Force Academy	31	31
Auburn	31	12
Coast Guard Academy	26	28
Military Academy	4	4
Missouri University of Science and Technology	19	14
Naval Academy	28	27
Smith College	4	2
Southern Methodist University	8	3
Stevens	20	20
Sweet Briar	4	3
University of Hawaii	4	1
University of Virginia	17	11
Total	196	156

Table 20: Baseline and Final Surveys

5.2 STUDENT AWARENESS OF DOD PROBLEM AREAS

One key goal of RT-19A was to expand the students' awareness of the number and variety of Department of Defense problem areas that require systems engineering expertise. To assess change, a question on both the pre- and post-surveys asked the students to list three engineering problems that they believed were currently being addressed by the Department of Defense. There were 74 matched pre- and post- survey responses to this question.

There were three changes from pre- to post-survey. First, on the pre-survey, 6.8% of the responses were blank, compared to only 3.2% on the post-survey, suggesting that the students felt prepared to think about the question. Second, this led to a slight increase (from 9.5% to 11.7%) in the number of non-specific responses that nevertheless referred to engineering areas—for example, problem areas described as “quality,” “electrical,” “institutions regarding the military,” “counter insurgency,” “setup of area,” or “structures.” Third, there was an increase in the percentage of students listed what were clearly systems engineering issues (“requirements management,” “project scheduling,” “systems integration,” “predictive decision algorithms”), with 14.4% providing this type of response on the pre-survey compared to 18% on the post-survey.

The specific areas, listed by 83.8% of students on the pre-survey and 85.1% on the post-survey, are described in Table 21.

Problem Area	**Including**
Energy related	Energy efficiency, green energy, renewable energy (solar), alternative energy, fuel economy
Weapons/weapons systems	Weapons acquisition, missile systems, fighter planes, ship propulsion, force modernization
Communication systems	Communication, communication networks, real- time information, inter-systems communication
Cyber security	Network security, secure communication, facial recognition software
Field needs	IED detection, troop protection, expeditionary housing, water filtration, lightweight armor
Autonomous vehicles	Unmanned aerial vehicles, military robotics
Humanitarian assistance	Humanitarian assistance, disaster relief, emergency shelters, phantom limb pain treatment
Systems engineering	Requirements management, requirements creep, system integration, not meeting deadlines, budgetary and logistical management of forces, infrastructure design and survivability/sustainability

Table 21: Problem Areas Listed by Students as DoD Problem Areas

The remaining changes were minor, with the greatest in the systems engineering and field needs areas (see Table 22).

	% pre-survey responses	% post-survey responses	% change
Systems engineering	14.4	18.0	3.6
Field needs	11.7	14.9	3.2
Communications	9.9	11.3	1.4
Humanitarian assistance	3.2	3.2	0
Weapons systems	19.8	18.9	-0.9
Autonomous vehicles	7.2	5.9	-1.3
Cyber security	6.8	5.4	-1.4
Energy-related	10.8	7.2	-3.6
Vague	9.5	11.7	2.2
Blanks	6.8	3.2	-3.6
TOTAL	100	100	

Table 22: Change in DoD Problem Areas Listed by Students

5.3 STUDENT PERCEPTIONS OF PROJECT SUCCESS

Over 75% of students of the 132 students who responded to a question on the final survey that asked them to rate their projects' success, using a scale from 1 to 5, gave their projects a 4 or 5. Almost none considered them complete failures.

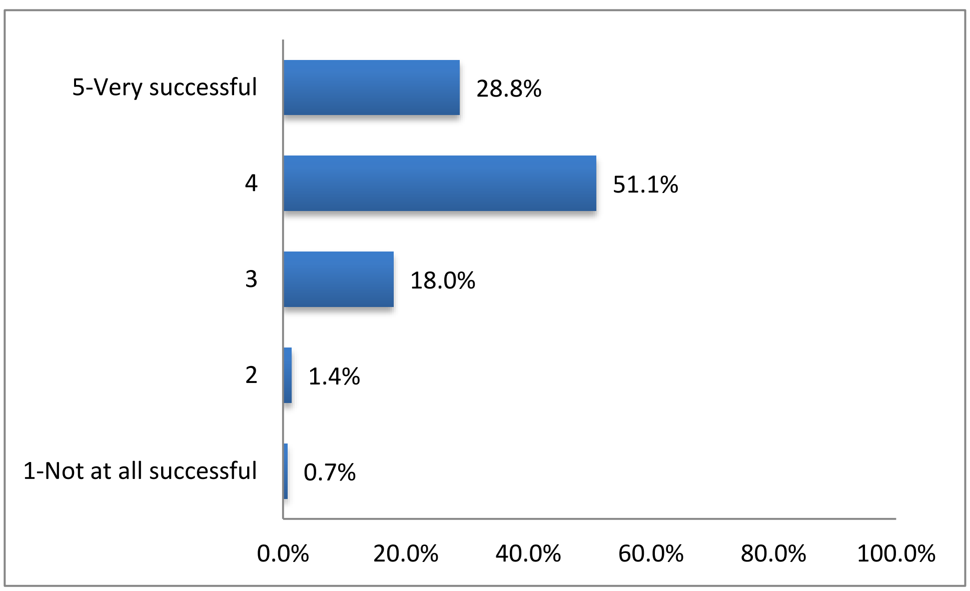

Figure 9: Student Ratings of Project Success

The reasons the students cited were similar to those cited by the PIs, including fulfilling requirements, working on real-life problems, building prototypes, experiencing the systems engineering process, and working together in teams.

A student at Stevens who rated his project a “5” provided a thoughtful response to the complexity afforded by the concept of “success” from a product as well as a teamwork perspective:

> This is a complicated question to answer. Success in a project could, on the surface, be determined purely by the outcome. From that point of view, we were very successful. We had nearly a half dozen engineering students readily able to answer deep questions about our design, and had a plethora of data and models to validate our assumptions. The group itself made the project successful as well. We came together in the last three or so months of the project to transform from 20+ students with 4+ different majors to a team that had one single agenda: To make the project work.

Students at University of Virginia and Sweet Briar were pleased that their designs showed a proof-of-concept, despite the phantom limb team’s inability to acquire IRB approval for human testing before the end of the semester:

> This capstone project allowed for a relatively true-to-industry systems design process that led to real results. Our project was successful in defining a problem, designing a solution, and validating concepts.
>
> While we were unable to test our design on amputees to see if it functioned as intended (alleviating phantom limb pain), we were able to show that virtual reality therapy can be an alternative to mirror box therapy.

One of the team at University of Virginia working on the Rapid Needs Adaptive Assessment Water (RANA) project discussed how managing to improve on the previous year’s designs using a systems engineering framework was a measure of success:

> We defined the problem, researched a topic that we had little familiarity with, brainstormed possible solutions (and detailed their construction), weighed and evaluated them based on our researched theory, and fully constructed and verified the operation of a solution. Since all of these were done systematically and professionally, I judge the project a success.

At the Coast Guard Academy, students described success as being able to meet their goals “safely and creatively” for multiple projects:

> [We were able to] construct a wind turbine almost entirely out of recycled materials to charge a 12 volt battery. The charging of the battery was very successful.
>
> Our project works for the most part, we could have come up with more refined and definite solutions for some of the problems we encountered, but everything we have put together has worked rather reliably. Success for our project is making sure that an unmanned vessel can link up with a docking station, recharge, and serve as a test platform to aid in harbor surveillance and response. In this regard I belief that we have

> achieved success as our boat works well and can dock and undock albeit not very smoothly.

Students at Missouri University of Science and Technology described how systems engineering concepts such as design constraints, the life cycle model, acquisitions, etc., contributed to their understanding of systems engineering, and that this made their project a success:

> This project has really given me a real world experience of how to incorporate the systems engineering process…this course has really defined and crafted my knowledge in the system design process--understanding the “Big Picture” concepts from the beginning of the acquisition through its life cycle.

> I was able to understand system engineering concepts and able to apply on a requirement based problem. Also was able to come up with a COTS solution within the constraints.

Other students discussed success in terms of communication and teamwork, as well as solving open-ended problems:

> Team bonding, team communication, team building were all great positives. The capstone of the water filtration device worked great! (Naval Academy)

> I define success as the take away lessons/feelings of the group. Whether or not the system actually worked is relative irrelevant to me because it was never going to be used in an operational sense anyway. The main purpose of the Capstone program

> (I think) is to develop skills in cadets that they otherwise would not have. (Air Force Academy)

> [I am now] much more comfortable in the engineering design and implementation process and more comfortable in entering this role in the air force. Gained the ability to be given a vague problem and go about solving it without much guidance and working as a team. (Air Force Academy)

> Our team had issues with getting parts and installing them. As far as how much we learned we were very successful. It was a great exercise in problem solving and dealing with ambiguity. (Auburn)

5.4 STUDENT PERCEPTIONS OF PROJECT CHALLENGES

Students across schools shared many of the same challenges, regardless of their status (graduate or undergraduate), engineering background, or whether they came from military or civilian schools. The challenges most frequently reported by the 138 students who responded to this question on the year-end survey were parts delays or difficulties with components acquisition (53.6%), time constraints (46.4%), and difficulties communicating with team members from different disciplines (40.6%).

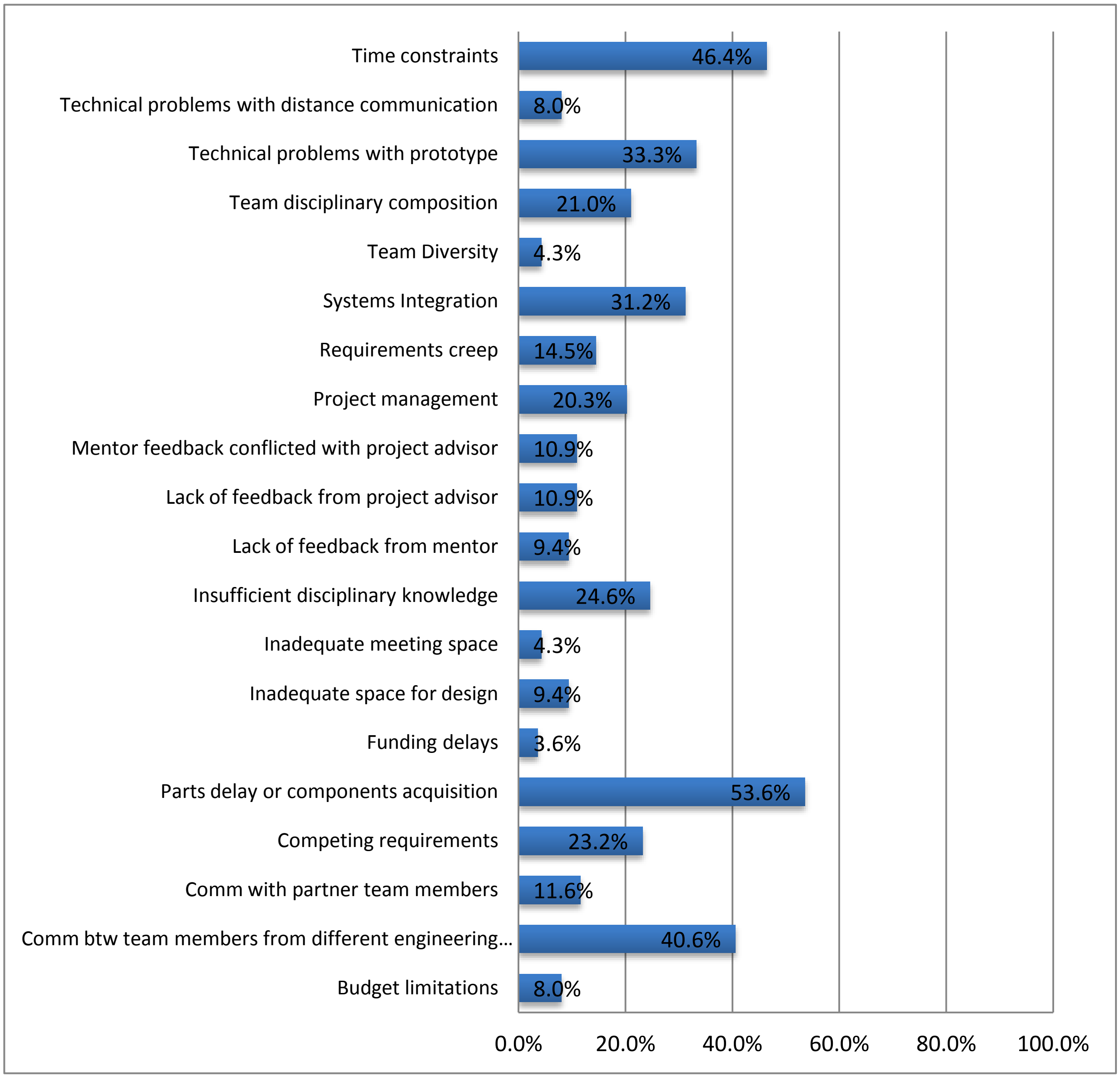

Figure 10: Student Perceptions of Project Challenges

The students attributed any lack of success to parts delays, the inability to build an operational prototype, or the inability to complete specific phases of the project, such as testing. Here are some examples:

> We learned a lot, but after months of design, fabrication, and testing, the project does not work. We ran out of time. We had to greatly reduce the scope of our project as the year wore on. (Coast Guard Academy)

> We lacked funds and time to completely finish what we had hoped, but we made it very far with what we had. (Connecticut College)

> We did not complete all the original aspects of the project, including full system integration and testing. We fell short on the decision algorithm and user interface portions. (University of Virginia)

> The project could have been more successful if there was more direct communication with the target customers and users of the system. (Stevens)

For partner schools in particular, an important challenge was communication over distance:

> Communication among each other was limited. Here at UH we did not get replies to emails and questions in a timely manner. (University of Hawaii)

5.5 STUDENT INTEREST IN SYSTEMS ENGINEERING CAREERS

However, although one important goal of both RT-19 and RT-19A was to increase student interest in systems engineering careers, the project cannot claim to have been successful in this regard. As we will see below, this may have been because many of the students—and particularly those who responded to both the pre- and post-surveys—were those already interested in systems engineering careers.

The pre- and post-course surveys included a series of questions designed to assess if there was a change in this area. The questions were as follows:

> On a scale of 1 to 5, with 5 being the highest, how interested are you in the following?
> Q1: Becoming a systems engineer
> Q2: Becoming a systems engineer for the government
> Q3: Becoming a systems engineer for private industry
>
> The 5-point scale ranged from "Not at all" (1) to "Very much" (5).

There were only 60 matched pre- and post-course responses to these questions, with some schools much more highly represented than others (see Table 23).

School	**# baseline surveys**	**# matched responses**
Air Force Academy	31	7
Auburn	31	5
Coast Guard Academy	26	1
Military Academy	4	4
Missouri Institute of Science and Technology	19	1
Naval Academy	28	18
Smith College	4	0
Southern Methodist University	8	2

Stevens	20	13
Sweet Briar	4	0
University of Hawaii	4	0
University of Virginia	17	9
TOTAL	196	60

Table 23: Matched Responses to Survey Questions on Interest in Systems Engineering

Since it seemed possible that the matched set of respondents was biased in one direction or the other, we compared the baseline (pre-course survey) responses for the matched set with the baseline responses for the entire set. This comparison confirmed the bias of the matched set, whose means scores on the baseline survey were higher than for the larger population of respondents.

	Q1
All respondents (n=177)	3.55 (SD: 1.30)
Matched set (n=60)	3.70 (SD: 1.27)
	Q2
All respondents (n=172)	3.16 (SD: 1.28)
Matched set (n=60)	3.27 (SD: 1.33)
	Q3
All respondents (n=176)	3.49 (SD: 1.23)
Matched set (n=60)	3.62 (SD: 1.22)

Table 24: Pre-course Results for All Respondents and Matched Set

While it might be expected that the means for the matched set would increase only marginally if at all, what is surprising is that in each case they decreased.

	Q1
Pre-course	3.70 (SD: 1.27)
Post-course	3.55 (SD: 1.44)
	Q2
Pre-course	3.27 (SD: 1.33)
Post-course	2.97 (SD: 1.41)
	Q3

Pre-course	3.62 (SD: 1.22)
Post-course	3.40 (SD: 1.43)

Table 25: Pre- and Post-course Results for Matched Set

Paired samples t-tests showed that the change from pre- to post- was not statistically significant ($p<.05$) for any question:

Q1: $t(60) = -0.15$, $p= 0.35$ for interest in becoming a systems engineer
Q2: $t(60) = -0.30$, $p= 0.09$ for interest in becoming a systems engineer for government
Q3: $t(60) = -0.22$, $p= 0.21$ for interest in becoming a systems engineering for private industry

Where there was change was in the mean scores for those who chose 1, 2, or 3 on the 5-point scale in the baseline survey. This change was statistically significant for interest in becoming a systems engineer for government:

Q1: Interest in becoming a systems engineer
Low: $t(12) = 1.39$, $p = 0.19$, increased, but no significance
Med: $t(11) = 1.90$, $p = 0.09$, increased, but no significance
High: $t(37) = -2.71$, $p = 0.01$, significant decrease

Q2: Interest in becoming a systems engineer for government
Low: $t(17) = 3.40$, $p = 0.004$ – significant increase
Med: $t(15) = -1.10$, $p = 0.288$ – decreased, but no significance
High: $t(28) = -3.401$, $p = 0.002$ – significant decrease

Q3: Interest in becoming a systems engineer for private industry
Low: $t(10) = 1.96$ $p = 0.081$, increased, but no significance
Med: $t(15) = 1.05$, $p = 0.31$, increased, but no significance
High: $t(35) = -2.54$, $p = 0.02$, significant decrease

5.6. STUDENT PERCEPTIONS OF THE USEFULNESS SYSTEMS ENGINEERING CONCEPTS

When asked on the post-survey, "How did learning systems engineering concepts inform the design and development of your capstone project?" students repeatedly described how the use of these concepts had helped them grasp the internal and external aspects of systems (subsystems and integrated components), the complexity of systems of a higher order (system of systems, or SoS), and the integration of different engineering disciplines in the design of such systems. Here are some examples:

> [Systems engineering] gave structure and order to the whole process. (Naval Academy)

> It made each of us think about how we should design our specific subsystems to work well with other subsystems. We communicated better knowing our actions would affect another person's work. (Air Force Academy)

> It helped our group look at the bigger picture. Our project included many components that needed to be tied together smoothly (i.e., pumps, piping, heaters). Systems engineering helped us consider the challenges of making these work in a single system. (Coast Guard Academy)

> It allowed our team to have both a broad view of the entire project and narrow views on specific components. (Sweet Briar)

> Learning systems engineering concepts helped me understand that our design was an iterative process with the team constantly feeding new information to make adjustments. Paying attention to stakeholder requirements and making sure there was a common thread that integrated all subsystems informed my thought process. (Stevens)

> Helped us cross the lines of our initial disciplines and learn multiple ways to approach the solution to our problems. (Naval Academy)

Students also felt that the analytical tools used in systems engineering were helpful, including test plans, matrices, and test cases; configuration management policies and technical performance measures; and systems requirements documents. These tools facilitated the organization of project timelines and budgets, with the final goal of delivering a functional and operational prototype to a real-life customer:

> We did a full life cycle systems development. We started from requirements and went to actually building a solution. (University of Virginia)

> [Systems engineering concepts] provided the 3 dimensional approach to looking at a problem and foreshadowing possible problems, bottlenecks, and delays. (Military Academy)

> Systems engineering concepts helped keep us on track and regulate the time and effort we would spend on each part of the project. (Missouri University of Science and Technology)

Finally, students underscored communication and teamwork as systems engineering concepts that supported their project efforts. Systems organization applied not only to the structure of physical design but also to various levels and operations of human organization:

> [Systems engineering concepts] helped me better communicate between partner sub-teams more effectively. (Naval Academy)

> [Systems engineering] gave the team understanding of the vitality of communication between subgroups. (Stevens)

> [Systems engineering] allowed us to realize that communication and collaboration between groups is essential. Newly acquired information in one subsystem should be brought up to other groups, as it usually is helpful for them too. (Stevens)

6.0 MENTORSHIPS

During RT-19, students interacted with several different types of mentors, including mentors assigned by the Department of Defense; industry mentors from defense-related and other corporations and industries, such as Boeing or Northrop Grumman; and internal mentors, who were often departmental advisors, graduate students, or faculty members. One recommendation for RT-19A, based on the experiences of faculty and students during RT-19, was that these mentorships be put in place for all schools and that student-mentor interactions should be "significant," meaning that the mentors should be easily available and the interaction between students and mentors should be frequent and helpful to the students. As a result, all but one of the participating schools had either a DoD or industry mentor and more than half had both DoD mentors and industry mentors (a complete list of mentors is included in the Appendix section of the report). About half had previously mentored RT-19 students.

The following section of the report is taken from the year-end faculty and student surveys, as well as a mentor survey sent in May 2012 that 18 mentors replied to. These asked about the following:

- Mentor types (DoD, industry, or internal) and their roles
- Mentor communication styles and frequency of communication
- Perceived success by mentors, PIs, and students of student projects

Although the mentors who responded to the survey are a subset of the total population of mentors and may therefore not be representative, there comments are consistent enough to be worthy of consideration.

In Table 26, mentors who responded to the survey are highlighted: DoD mentors in blue (six); industry mentors in green (six); and faculty or internal institutional mentors in yellow (seven). About half of the mentors who responded to the survey had previously mentored RT-19 students.

6.1 MENTOR ROLES

There were two promising practices regarding mentors. One was that mentors meet frequently with the student teams and the second was that they serve as reviewers at design reviews. It is clear from the mentor surveys that the mentorships were more effective this year than last, primarily because relationships were established earlier. Based on their survey responses, some of the mentors (DoD, industry, and internal) saw themselves as "coaches," providing feedback and technical assistance throughout the semester, on a weekly or monthly basis. Others played the role of "customers" or "clients" and met with students less frequently. Mentors who played more of a remote client role provided requirements at the beginning of the project, offered occasional technical advice during the semester, feedback at the midpoint, and attended the final design review. In some instances, mentors served as both clients and coaches. Schools with mentors of the first type included Auburn, Coast Guard Academy, Naval Academy, Southern

University	Mentor name	Organization	Area of expertise
Air Force Academy	Bryan Cooper, Instructor	US Air Force Academy	Electrical engineering
Auburn	Jeremy Barnes, Teaching Assistant	Auburn	Systems Engineering
Auburn	William Simon, GRA	Auburn	Computer Science
Coast Guard Academy	Chris Lund, Research Engineer	USCG R&D center	Civil Engineering
Coast Guard Academy	Scot T. Tripp, Program Manager	USCG R&D center	Ocean Engineering
Coast Guard Academy	Brent Fike	USCG R&D center	Mechanical Engineering
Military Academy	Bill Crawford, Engineer	AMRDEC	Systems engineering
Missouri University of Science and Technology (MUST)	Paul Barnes, Power Components	Army Research Lab	Electrical, Materials
MUST	Mike McClelland	Boeing	Systems Engineering
MUST	Lou Pape, Associate Technical Fellow	Boeing	Systems Engineering
MUST	Robert Scheurer, Systems Engineering Function	Boeing	Systems Engineering Electrical Engineering
MUST	Neil Whipple, Engineer	Boeing	Avionics Integration
MUST	Nancy, Director in Advance Design	Boeing	Electrical Engineering
Naval Academy	John Schedel, Project advisor	US Naval Academy	Mechanical
Southern Methodist University	Michael D. Woodman, Director, Defense Solutions	Design Interactive, Inc.	Industrial (Interactive Simulation)
Stevens	George Isabella, Manager; Test Equipment Engineering / Defense Specialties Engineering	BAE Systems	Manager; Test Equipment Engineering / Defense Specialties Engineering
University of Hawaii	Michael D. Woodman, Director, Defense Solutions	Design Interactive, Inc.	Industrial (interactive simulation)
University of Virginia	Bill Campbell, Systems Engineer	Combat Direction Systems Activity Virginia Beach VA	Systems engineering and communication systems
Naval Postgraduate School Sweet Briar University of Virginia	Kim Watkins	OSD (AT&L) reserve support	Systems Engineering Electrical Engineering CS&E

Table 26: Mentor Survey Respondents

Methodist University/University of Hawaii Manoa, Air Force Academy, Missouri University of Science and Technology, Coast Guard Academy, and University of Virginia/Sweet Briar. Schools with mentors of the second type included Coast Guard Academy, Stevens, and Military Academy. Missouri University of Science and Technology had one mentor of each type. Figure11 analyzes the mentor responses to a question that asked what roles they played.

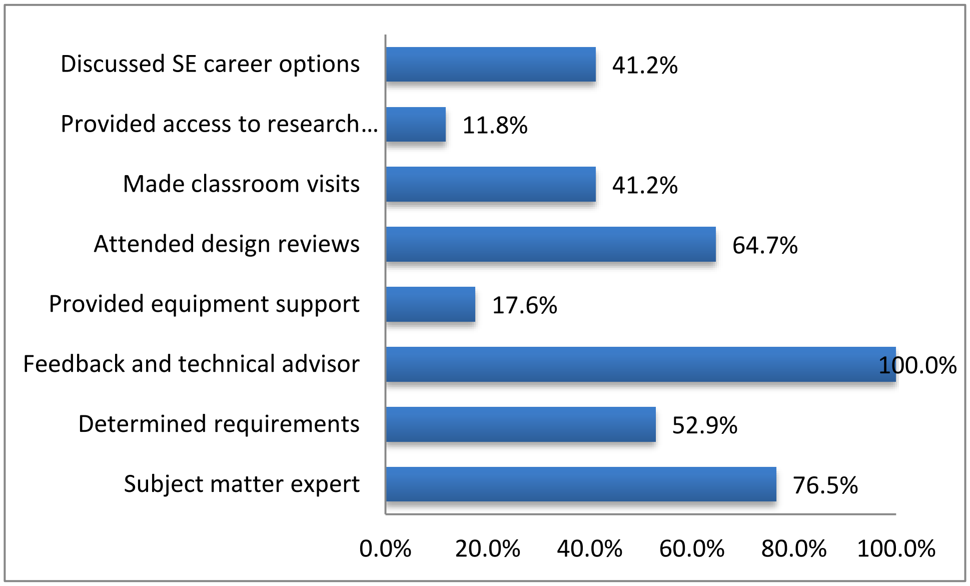

Figure 11: Mentor Roles

Almost all of the mentors reported that they communicated with the students by email, but almost two-thirds paid personal visits and almost half used the telephone (see Figure 12).

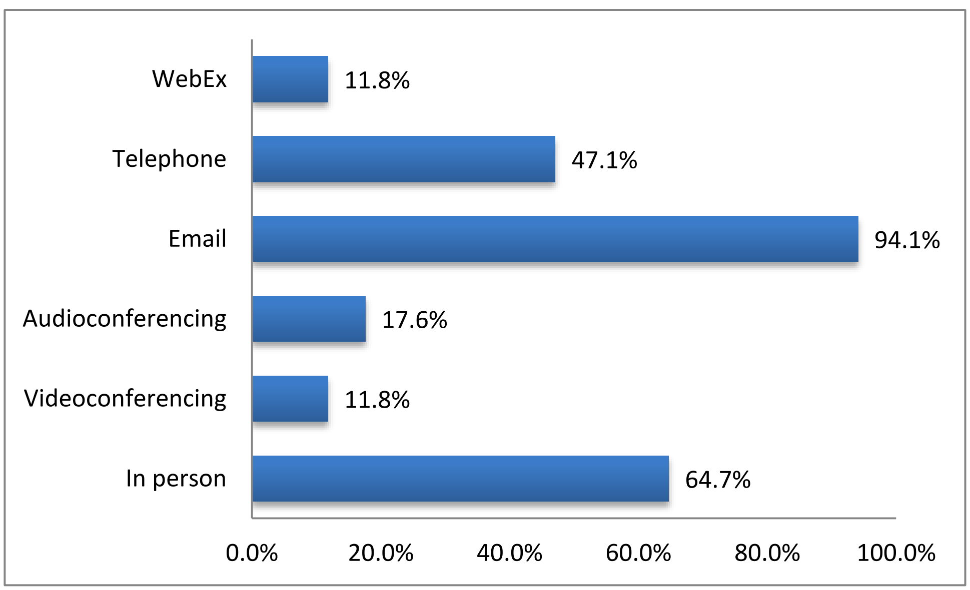

Figure 12: Types of Mentor-Student Interaction

6.2 DOD MENTORS

The DoD mentorships had been problematic during RT-19, in part because they had been difficult to establish. This year, nine PIs reported that they had DoD mentors. One university (Auburn) and three of the four partner schools did not (Connecticut College, University of Rhode Island, and Smith College). However, Auburn instead had an advisory board that included military personnel. One of the partner schools (Smith) had expressed the desire for a DoD mentor, but the others were associated with military institutions and may not have felt the need.

DoD mentors were selected for a variety of reasons, including personal interest in the students' projects and/or the chosen problem area (for example, CDR Kim Watkins' interest in the immersive technologies being developed at Southern Methodist University). At two schools (Military Academy, University of Virginia), the mentors had previously lent their expertise to RT-19 students.

The seven DoD mentors who responded to the survey reported many of the same roles as the entire mentor group, but were more likely to attend design reviews, provide equipment support, and act as clients. They were less likely to and discuss career options or make classroom visits.

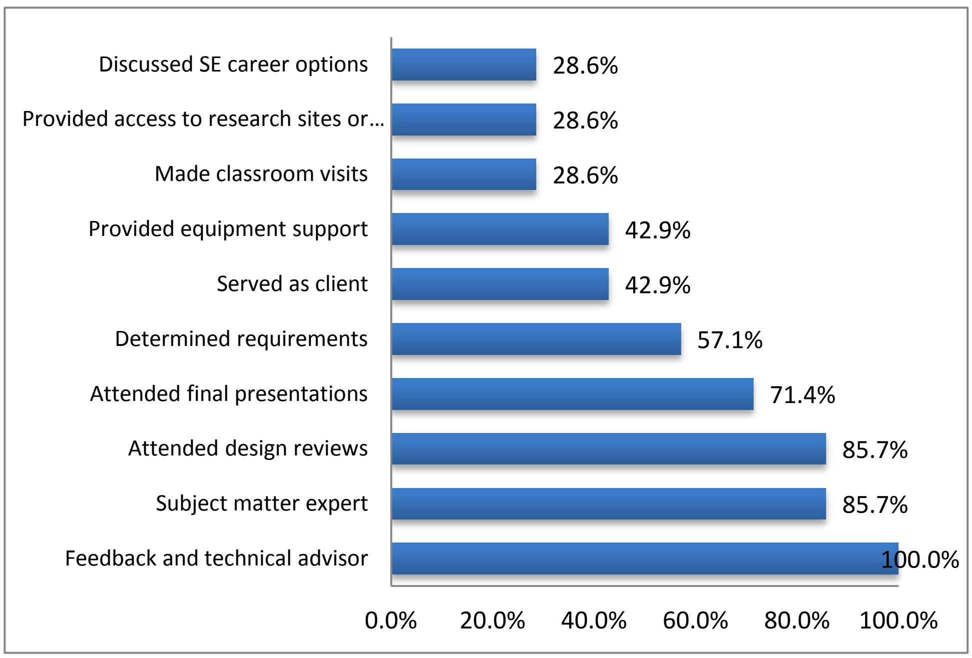

Figure 13: DoD Mentor Roles[1]

Table 28 includes the DoD mentors' descriptions of the type of frequency of communication with the students they were mentoring.

[1]Two DoD mentors did not answer this question.

University	Type of DoD mentor communication
Coast Guard Academy	Weekly telephone and email exchange, and campus visits and off-campus. Served as client, subject matter expert. Determined requirements, gave feedback and technical advice, provided equipment support and access to workplace. Attended design reviews.
Military Academy	Monthly communication by email and one campus visit. Gave feedback and technical advice and attended design reviews.
Missouri University of Science and Technology	Functioned as part of the student design team. Weekly communication by WebEx conferencing, email, telephone and videoconference and through a shared online portal. Served as subject matter expert, helped determine requirements, gave feedback and technical advice, and attended design reviews.
Naval Academy[2]	Daily face-to-face, web and phone exchanges. Served as subject matter expert, gave feedback and technical advice, provided equipment support, attended design reviews and presentations, and discussed systems engineering career options.
Southern Methodist University	Communicated with students a few times during the semester via email, teleconference, and a shared online portal. Served as subject matter expert, delivering feedback and technical advice. Visited campus.
University of Hawaii	Communicated with students a few times during the semester via email, teleconference, and a shared online portal, and a campus visit. Served as client and subject matter expert, gave feedback and technical advice, and discussed systems engineering careers.
University of Virginia	Communicated via email, telephone and teleconference a few times a semester and visited campus. Students visited mentor off campus. Helped determine requirements, gave feedback and technical advice, and attended design reviews.

Table 28: DoD Mentor Descriptions of Roles and Communication

6.3 INDUSTRY MENTORS

Eleven PIs reported that they had industry mentors who assisted student teams and faculty as consultants or technical advisors on school-specific technologies and research areas, including wind turbine technology (Coast Guard Academy), electrical engineering (Air Force Academy), water purification technology (Naval Academy), software systems assurance consultation (University of Hawaii Manoa), or disaster relief (Stevens), and systems engineering (Auburn, Military Academy, Missouri

[2] In this case, the DoD mentor was internal to school and not assigned.

University of Science and Technology, Sweet Briar, University of Virginia). At three schools (Missouri University of Science and Technology, Southern Methodist University, University of Virginia), the industry mentors carried over from RT-19. Two of the four partner schools did not have industry mentors.

Most of the industry mentors who responded to a question on the survey that asked what roles they had played reported that they had played many of the same roles as the DoD mentors, although they were understandably less likely to serve as clients.

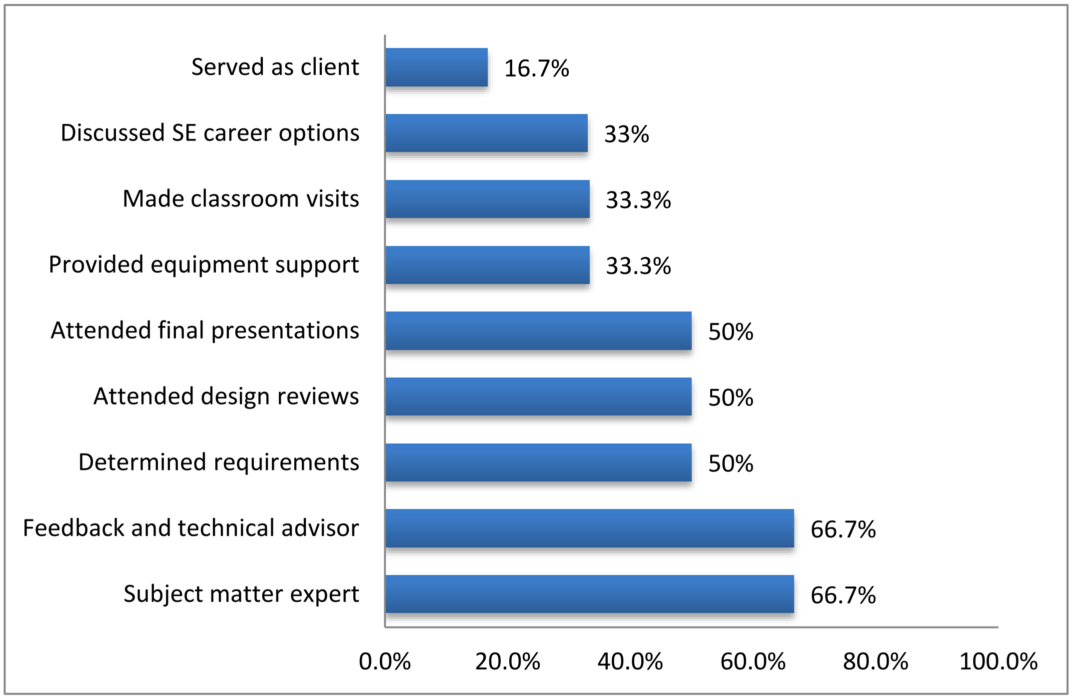

Figure 14: Industry Mentor Roles

And as was the case with the DoD mentors, the roles, frequency and type of communication with the industry mentors varied from mentor to mentor.

University	Type of Industry mentor communication
Air Force Academy	On campus visit. Gave feedback and technical advice.
Auburn	On campus few times during the semester. Gave feedback and technical advice, presented in class and discussed systems engineering careers.
Coast Guard Academy	Weekly telephone and email exchange. Served as subject matter expert. Gave feedback and technical advice, provided access to workplace and attended design reviews.
Military Academy	Biweekly communication with telephone, email, teleconference, and a campus visit. Served as subject matter expert, helped determine requirements, gave feedback and technical advice, equipment

	support, and attended design reviews.
Missouri University of Science and Technology	Weekly communication by email, telephone and teleconference and shared online portal. Served as client, helped determine requirements, gave feedback and technical advice, and attended design reviews, and discussed systems engineering careers.
Naval Academy	Email and telephone communication a few times a semester. Served as subject matter expert, helped determine requirements, gave feedback and technical advice, and provided equipment support.
Southern Methodist University	Communicated with students a few times during the semester on email, videoconference, and campus visit. Served as subject matter expert, gave feedback and technical advice, and discussed systems engineering careers.
Stevens	Communicated with students a few times a semester by email and visited campus. Served as subject matter expert, helped determine requirements, attended design reviews, gave feedback and technical advice, and discussed systems engineering careers.
Sweet Briar	Students visited off-campus a few times a semester. Served as client and subject matter expert. Gave feedback and technical advice, attended design reviews, and discussed systems engineering careers.
University of Hawaii	Communicated a few times during the semester by email, telephone and through a shared online portal. Served as subject matter expert, helped determine requirements, gave feedback and technical advice, and discussed systems engineering careers
University of Virginia	Communicated via telephone and teleconference a few times a semester and campus visit. Students visited mentor off campus. Helped determine requirements, gave feedback and technical advice, and attended design reviews.

Table 29: Industry Mentor Descriptions of Roles and Communication

6.4 MENTOR PERCEPTIONS OF STUDENT SUCCESS

Almost three-quarters of the 15 mentors who responded to the a question on the survey that asked them to rate the students' projects gave them ratings on the higher end (4-5) of a five-point scale that ranged from Not successful to Very successful.

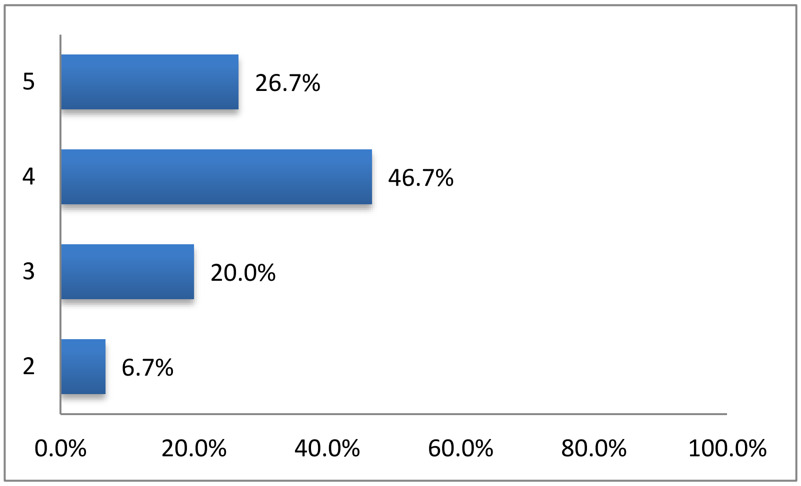

Figure 15: Mentor Perception of Project Success

The responding mentors used words such as "interesting," "challenging," and "useful" to describe the students' projects. Many evaluated the students' based on their ability to meet requirements within a limited timeframe. Here are some sample responses:

> The students seemed to have a solid understanding of their objectives.
>
> The students did a great job of trying to meet the requirements with the limited resources available. Their enthusiasm and innovation made up for much of it.
>
> The final products produced by the teams are among the best student-build projects I have ever seen. The students did a great job of staying focused on customer requirements throughout the project, and it shows in their end result.
>
> Their projects were very interesting and challenging. I believe that it really put them in the shoes of a system engineer. They were able to see how systems engineering practices could be used to help them to meet their goals in a very practical way. In the end I was very happy with the progress they made and the final system which was produced.

However, the mentors rated the students' mastery of systems engineering lower than they rated the success of their projects, with over three-quarters giving the students a 3 or 4 on a 5-point scale (see Figure 16).

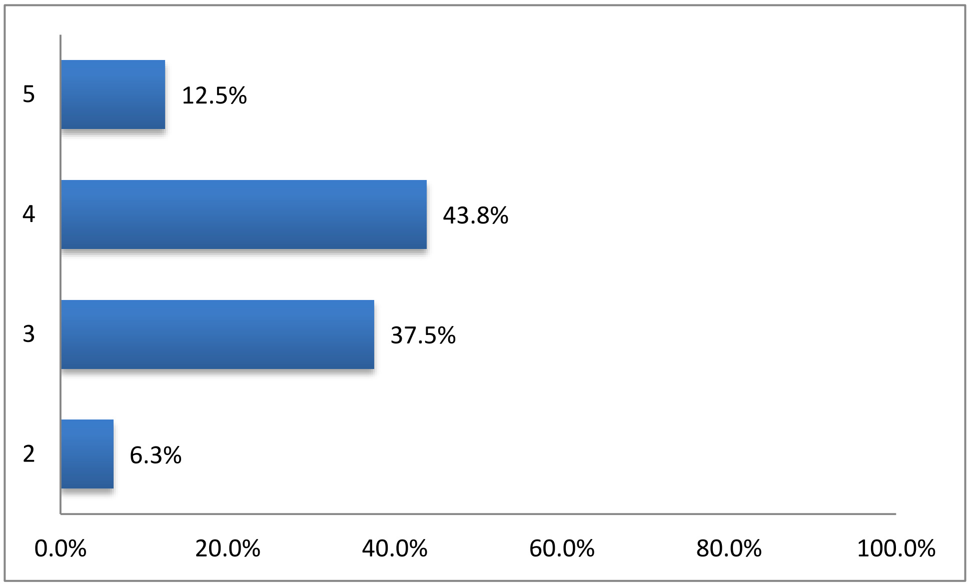

Figure 16: Mentor Perceptions of Student Mastery of Systems Engineering Concepts

Their comments generally reflected the belief that too much could not be expected from undergraduates:

> Most of the students had minimal background with systems engineering going into the project, but they really seemed to embrace it and put it into great use.
>
> Difficult to go into depth on a project in this short time period - given the amount of time most students have available to devote to one class - also I consider Systems Engineering more an on-the-job career learning experience. It cannot be easily picked up in an academic setting.
>
> I rate this low because of personal experience and opinions. I'm dealing with undergraduate students. It has been my experience (which has led me to my current opinion) that undergraduate students cannot MASTER the concepts and skills of systems engineering due to their lack of exposure and experience in the industry. I think these studies get healthy INTRODUCTIONS to the concepts and skills but they cannot be MASTERED without real world application and experience.
>
> Certainly, they learned a lot, but it takes a while to actually master a skill.

Despite the fact that there was a greater mentor presence for RT-19A compared to RT-19, well over three-quarters (81%) of the mentors reported that they would have liked more in-person and regularly spaced interaction with the students but had been prevented from doing so because of their own travel schedules and commitments that conflicted with the teams' more rigid schedules, necessitated by a need to keep to their timelines. Several noted that in the future it would be better to plan for formal meetings on a regular basis, with both faculty and students scheduling "times in advance for meetings and milestone dates." Mentors wanted to meet earlier and more frequently:

> Work more closely with the students during their fall semester. Contribute more time to present systems engineering fundamentals and volunteer to be a guest speaker/lecturer more frequently.

> I started meeting with my mentees in person about a month into the semester. This turned out to be our most valuable means of communicating and interacting with each other. For this reason I would start these meetings as early as possible next time.

One mentor also noted how important it was to provide explicit technical feedback when needed, but also to allow the students to come up with solutions for themselves while pointing them in the right direction. On the other hand, another mentor felt that students should not be afraid to seek their advice regularly, "regardless of age differences or gaps in expertise."

Overall, the mentors felt that the experience had definitely been worthwhile. One mentor wrote that bringing together military and industry professionals was "priceless," while another described how RT-19A afforded the opportunity for different groups to "communicate," providing pathways for students to "learn practical skills" and "gain exposure to the real world." The relationship was also described as

> … a win-win situation. It keeps industry professionals up to date with current course work in the universities. It also provides the students [with] an inside look to how the projects and systems are worked given the constraints of a company--where things are built, not just on paper.

6.5 FACULTY EVALUATION OF MENTOR ROLE

Six of the nine faculty who responded to the final survey wrote that they felt that the mentorships (industry, DoD, and internal) had been successful, "highly effective," or "efficient." They each described a slightly different role for their mentors. For example, at University of Virginia, the industry mentors played somewhat different roles depending which of the two projects they were advising. Thus one mentor from Northrop-Grumman attended the students' interim design reviews, while experts at the Pain Management Clinic at University of Virginia helped students working on the Phantom Limb project learn about current treatments and practices in the field. There was a similar division of responsibility between the two DoD mentors:

> Our primary DoD Mentor, Bill Campbell, has been a strong contributor to the program. He has attended design reviews by the teams and given constructive advice to the teams. In terms of suggestions/instructions, the main point would be for the DoD mentor to proactively engage with the student teams. Bill's proactive attitude – not waiting for the teams to ask for something specific – has proven important both this year and last. In addition, Colonel Nancy Grandy has served as a mentor for the Rapid Adaptive Needs Assessment project. She met with the team twice, providing feedback to the team and talking extensively with the students about their experience. Having someone with such project-specific knowledge to share with the team was very valuable.

The PI at Southern Methodist University reported that their mentors had kicked off the DoD projects, motivated students, elaborated top-tier requirements, and helped teams acquire VBS2 and Fusion software licenses. Missouri University of Science and Technology mentors were considered part of student teams and attended weekly design group meetings via WebEx.

At University of Hawaii Manoa, the mentor's face-to-face visit with students was critical in validating their role in a project that was spread over a vast distance (see below for the discussion of this type of partnership).

The PI at the Naval Academy felt that one of the most important mentor roles was to ask students "bigger picture" questions, as well as detailed technical ones, in order to provide students with the most valuable advice:

> The mentors were highly effective at providing technical advice and troubleshooting for the students. Their experience level is highly valuable to the students, who are not only executing a major project for the first time but are also learning new subjects in order to execute the project. The best suggestion I can give to future mentors is to try to get the students to explain the big picture of what they are trying to do, as well as the particular details. Often, the students would go to a mentor with a detailed question and spend lots of time trying to determine an answer together. Often, better recognition of the big picture reason for the detailed question would have led to a significantly different, better, simpler solution, aided by the mentor's experience.

At Auburn, where there were no specific mentors but instead an advisory panel of engineers and defense contractors from various government agencies (US Army Aviation and Missile Command, Missile Defense Agency, NASA, Northrup-Grumman, and Frontier Technology, among others), the PI reported that the students had responded well to the systems engineering presentations and feedback from this group.

Other schools had more mixed success with their mentors. At the Military Academy, the PI described how their mentors had helped run the design competition between the Army, Navy, and Air Force Academy but noted that their direct interactions with the students had been only "moderately successful" and would have been better had "the mentor demanded more updates from the students." Coast Guard Academy recommended that in the future a systems engineering mentor be included, in part to support students with a career lecture on systems engineering. The Stevens PI felt that the lack of a [DoD] mentor was a "critical component missing from the project," while the Smith PI noted that not having a DoD mentor was a major disappointment for the students.

6.6 STUDENT ASSESSMENT OF MENTOR VALUE

About two-thirds (65%) of the students who responded to the year-end survey, and 87% of those who responded to the question, felt that mentor feedback had helped them with their projects.

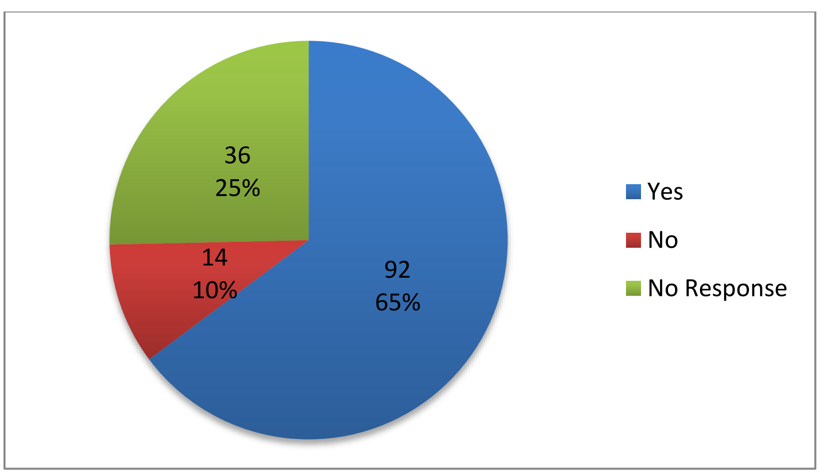

Figure 17: Student Assessment of Mentor Value

For the students, the most frequently mentioned mentor role was as technical advisor, followed by help determining requirements and attending design reviews:

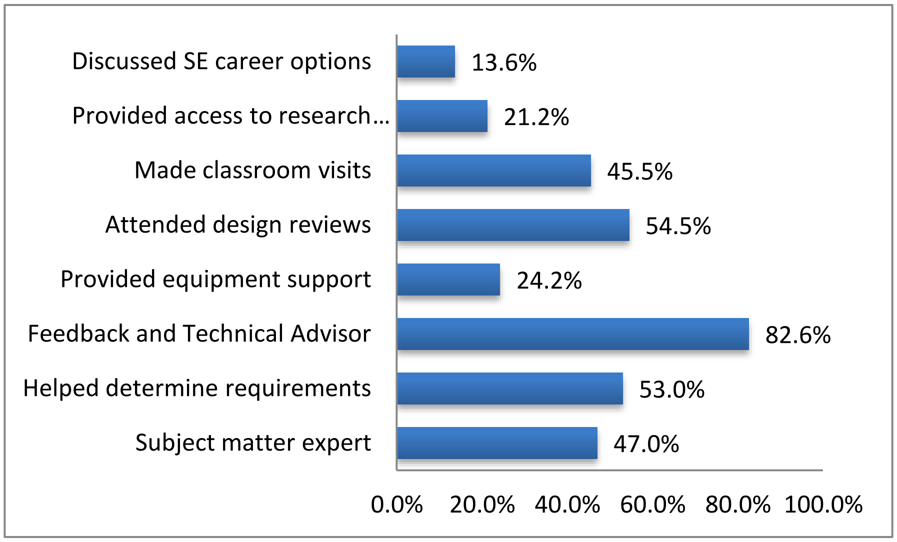

Figure 18: Student Perception of Mentor Roles

Students listed in-person visits and email exchanges as the most common forms of interaction with their mentors, with all other types of interaction used far less frequently. More of the mentors felt they used email with the students (94%) than students felt they used email with their mentors (61%), while more of the students felt they met in person with the mentors (80%) than mentors felt they met in person with the students (65%). This may have been because of the lack of match between the mentor and student populations or a perception of the value of a particular type of interaction.

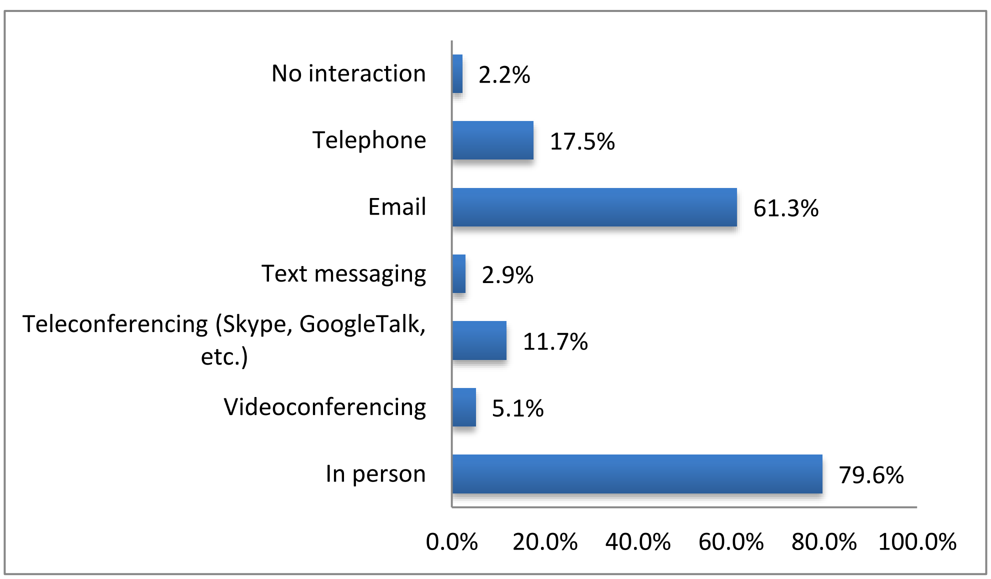

Figure 19: Types of Student-Mentor Interaction

7.0 PARTNERSHIP CASE STUDIES

One goal of RT-19A was to pilot a partnership model, whereby a school that had participated successfully in RT-19 would extend its reach by partnering with one or more non-systems engineering schools. As a result, five lead schools–Auburn, the Coast Guard Academy, the Naval Academy, Southern Methodist University, and the University of Virginia–recruited partner schools. Four recruited one partner and one (Coast Guard Academy) recruited two, for a total of six partner schools.

Eleven faculty and 22 students participated from the partner schools. The table below lists the number of partnering faculty and students by school:

RT-19A Lead School/Partner	# of partner faculty	# of partner students
Auburn – Tuskegee University	2	0
Coast Guard Academy – Connecticut College, University of Rhode Island,	2	10
Naval Academy – Smith College	1	4
Southern Methodist University – University of Hawaii Manoa	1	4
University of Virginia – Sweet Briar	2	4
TOTAL	11	22

Table 31: Number of Faculty and Students at Partner Schools

The section that follows is based on interviews with the PIs from all but one of the lead and partner schools (the exception was Tuskegee), from the PI interim and final surveys, and from discussions at the year-end workshop.

There were two different types of partnership: Student-to-student partnerships (Coast Guard Academy-Connecticut College-University of Rhode Island; Naval Academy-Smith College; Southern Methodist University-University of Hawaii Manoa; University of Virginia-Sweet Briar) and faculty-to-faculty partnerships (Auburn-Tuskegee University). In addition, there were several variations on the student-student partnership model. The faculty-to-faculty partnership model was unique to Auburn and Tuskegee, with Auburn providing a professional development opportunity for faculty rather than a capstone experience for students.

7.1 STUDENT-TO-STUDENT PARTNERSHIPS

University of Virginia
(partnering with Sweet Briar)
The partnership between Sweet Briar, a small liberal arts women's college based in Virginia, and University of Virginia emerged out of a conversation that began at the April 2011 SIEDS Conference. Scott Pierce, Associate Professor of Engineering at Sweet Briar, and Reid Bailey at University of Virginia discussed the possibility of forming a University of Virginia and Sweet Briar capstone partnership. Over

the next several months, two faculty members in the Sweet Briar Engineering department met several times in person and over the phone with University of Virginia faculty in the Systems Engineering department to draft the RT-19A proposal. The problem areas were motivating factors for faculty members at Sweet Briar: one faculty member's research aligned with the water quality problem area, while the other expressed interest in the prosthetics/assistive technologies project.

Initially, both PIs had to decide if they wanted students to work as a single group or to have students from Sweet Briar in a subcontractor role. It was decided that teams should include students from both schools so that they would learn to collaborate over geographic distance. A faculty member from each school acted as co-adviser to one of the two problem areas.

Team disciplinary composition was somewhat mixed: students at University of Virginia were predominantly systems engineering majors, with a few electrical and biomedical engineering students included, whereas students from Sweet Briar were all mechanical engineering majors. Sweet Briar students therefore worked primarily on the mechanical engineering aspects of the prototypes while University of Virginia students worked on the systems engineering and electrical engineering aspects.

PIs from both schools believed that peer mentorship and "just-in-time learning," rather than formal lectures, were the most effective ways for students to learn systems engineering concepts. They also decided that on a flexible, rotating management structure. As a result, facilitators and project managers on each team traded off each week so all the students experienced leadership roles at some point during the semester.

Students spent the first two weeks of the fall semester reading papers about their problem areas and creating flexible subgroups (i.e., visualization, virtual environments) that then changed as time went on. When students encountered questions or problems during the design process, they asked their peers or their instructors/advisors about related systems engineering concepts or specific disciplinary or technical knowledge. Throughout the design process, students learned about operations documents, requirements analysis, and other commonly used systems engineering tools.

Students met at least once a week with their local teams and also talked with their extended teams several times a week by conference call and through email. They also met face-to-face several times during the semester to hand off prototypes. A University of Virginia collaboration tool--a "wiki" / document repository where students shared calculations, presentations, etc. – was used by students on both teams. The PIs required that each team post a weekly summary of what had been accomplished.

The PIs from both schools described the project as mutually beneficial for students and faculty. As immediate next steps, the PIs at University of Virginia planned to bring the phantom limb prototype to a nearby hospital for veterans for additional testing and further technical exploration, while the collaboration led one Sweet Briar student to enroll in the Masters Program in Systems Engineering at University of Virginia.

Southern Methodist University
(partnering with University of Hawaii)

The PI from Southern Methodist University is an assistant professor in the Department of Computer Science and Engineering and was a participant in RT19 while the partner PI is an associate professor in the Department of Information Systems Management in the Shidler College of Business at the University of Hawaii-Manoa. They had known each other at the University of Southern California and both had industry experience. They had wanted to work together for some time in order to give their respective students an opportunity to collaborate across a distance, an experience they had had in industry in negotiating the differences between systems assurance and systems development teams. However, they had to devise a way to bring together two sets of students with very divergent interests, background knowledge, and academic goals. The Southern Methodist University students were mostly in computer science while the University of Hawaii-Manoa students were more business-oriented, with no computer science background. The two PIs solved this problem by assigning the Hawaii students the role of systems assurance, a part of systems engineering that both PIs felt does not receive the emphasis it should.

The greatest hurdle they faced was building trust between the two groups. The Southern Methodist University teams liked the idea of collaborating with the UHM teams but were not convinced that the UHM students had the technical expertise to play a systems assurance role on such a technical project. The UHM students were equally motivated but did not at first understand their role or see how they were going to be useful.

The two PIs quickly realized that this partnership required each group to educate itself about the other. The Hawaii PI had to introduce systems assurance into his courses, while the Southern Methodist University PI had to convince her students that systems assurance was necessary. Building trust was not facilitated by the fact that the Southern Methodist University students repeatedly failed to meet delivery deadlines—and to inform the UHM students about what was happening. The UHM students then found themselves waiting on the Southern Methodist University students, leading them to have trouble meeting their own course requirements. In the end, the UHM PI had to devise a back-up plan so that his students could complete their courses and receive grades.

It was not until the client made a trip to the University of Hawaii in the spring semester that the UHM students really came to understand the project and to believe in the value of their own role. This visit also made the Southern Methodist University students take the UHM students more seriously. The UHM students realized that they had had many of the same questions as the client did and became much more assertive, forcing the Southern Methodist University design team to spell out their own rationale for the decisions they had made. In the end, the Southern Methodist University students felt they had benefitted from this exchange.

Although the physical distance and lack of familiarity made trust difficult, both PIs felt that the fact that the two groups were in different geographical places and did not know each other was in the end a major benefit, because they did not hold back for fear of losing friends.

In reflecting on the difficulties the groups had faced during the year, both PIs felt that they would have been mitigated if the groups had been forced to work together earlier in the year and if the client had been able to visit both groups earlier. As one wrote in a survey response:

> …students [should] meet with the client very early on, perhaps during the assurance planning task. Meeting the client and hearing directly from him about client concerns and their role on the project very much increased the students' confidence and motivation for the project.

In addition, although communication improved greatly in the spring semester, it varied by group. The SMU PI noted that the team that had more trust in its collaborators did better in the end--they got more help, which led to a better result.

Despite these difficulties, both PIs felt the having one group act as system assurance for another group was a promising model, one that they plan to continue in the future.

United States Coast Guard Academy
(partnering with Connecticut College and University of Rhode Island)

In the case of the Coast Guard Academy and its partners (University of Rhode Island and Connecticut College), the faculty originally divided the project into subsystems so that each student team at each school could develop a design for the subsystem assigned to it. For example, Coast Guard Academy cadets were to design a water-based vessel and control system for electronic navigation. The University of Rhode Island students were to design a system for using vision to navigate to a target. By combining the two systems, the students would be able to synthesize a system that could navigate to a point on water, maintain station-keeping at that point, and then navigate to a docking station, first using GPS and DGPS signals to get close, then using vision to complete docking. Connecticut College was to provide the software so multiple autonomous vessels could collaborate.

The rationale behind pursuing three independent systems was explained by the Coast Guard Academy PI:

> Each school created a parallel solution that complements solutions from other schools. They generated complementary designs that did not have another school's design solution in the critical path. This approach allowed each school to create a partial design that could be fitted with a complementary design from another school to complete the final design. University of Rhode Island focused on autonomous systems that could communicate and use vision to navigate to a target. Connecticut College focused on autonomous systems that could collaborate on a goal. The Coast Guard Academy focused on autonomous systems that could maintain station and formation using electronic navigation systems

Due to problems in funding, the two partner schools were not able to contribute to the project to the extent planned. The University of Rhode Island students developed three land-based systems but never transferred those systems to water-based vehicles. The Connecticut College students configured a remote-controlled sailboat for autonomous operation as an independent study.

The original plan for the project would have necessitated a great deal of communication between student teams, both face-to-face and virtually. Although a few face-to-face meetings were held at the start of the year, funding problems put a stop to ongoing communication between the teams.

Naval Academy
(partnering with Smith College)

The PIs at the Naval Academy and Smith had met briefly when the Naval Academy PI visited Smith, a women's liberal arts school, on personal business and both expressed an interest in working together. For the PI at Smith, this was an opportunity for her students to work with engineering students beyond the confines of Smith's small general engineering program. For the PI at the Naval Academy, it provided an opportunity to explore a partnership arrangement. The model they agreed upon was to have Smith students acting as subcontractors for the Naval Academy. Thus the Smith College team was designated as its own sub-team and put in charge of creating a secondary power supply for one of the Naval Academy teams. The faculty communicated through conference calls and the teams met face-to-face, with the Smith students traveling to Annapolis. Unfortunately, the Smith team then ran into funding problems, which made it difficult for them to complete their assigned tasks in a timely manner. Thus while they were able to produce a secondary power supply, they were not able to integrate their work into the system developed by the Naval Academy students.

7.2 FACULTY-FACULTY PARTNERSHIP

Auburn
(partnering with Tuskegee Institute)
In June 2011, the PI at Auburn discussed the possibility of a faculty partnership with two professors in the Computer Science Department at Tuskegee University. At the time, students at Auburn were completing the RT-19 capstone and the Auburn PI was developing the RT-19A proposal to create an UAV with secure ground communication as their RT-19A prototype. Auburn and Tuskegee had an institutional relationship prior to this, since a professor in the Systems Engineering Department at Auburn had previously worked with a professor at Tuskegee University to involve Tuskegee computer science students in information assurance and network protection. In this case, the two Tuskegee faculty members were interested in the secure end of computing-intensive systems and how to apply the systems engineering / secure computing systems material to their security courses. They also wanted to bridge computer science and systems engineering courses at their own school. They therefore arranged to observe and advise the Auburn faculty team on (1) the quality of the systems engineering course and (2) how best to position the course material for use by another university. All parties agreed to a professional development-mentorship relationship, with Tuskegee assuming the following responsibilities as outlined in the proposal:

(1) Verify that the course sequence achieves stated education objectives
(2) Provide recommendations on how to position the course material for use by another university

Over the course of RT-19A, PIs at both schools met face-to-face, had conference calls, and communicated by email. The Auburn faculty videotaped their courses, while Tuskegee faculty acted as observers and “a second set of eyes on the course,” watching the videos and assessing whether the Auburn faculty had met their educational objectives. The Tuskegee faculty attended two teleconferences a semester with the Auburn Industrial Advisory Board. In addition, the Tuskegee faculty participated in fall student design reviews, attended student presentations, and met with the student teams to help them select the final UAV design for prototyping. The vocabulary and content knowledge of systems engineering was not a problem for the Tuskegee faculty because they understood the vocabulary of computer science and software engineering (computer hardware and software vocabulary). Faculty from Auburn reciprocated and met with students in the computer science department at Tuskegee to share information about the systems engineering discipline. Tuskegee used part of their grant funds to buy materials so that they could offer a systems engineering course that would mirror Auburn’s fall course, also focused on designing a UAV with secure ground communication.

According to the Auburn PI, the partnership was an effective faculty-to-faculty professional development and mentorship opportunity because it was not a curricular or instructional burden for PIs to contribute and because it fit both institutional contexts and student needs.

7.3 WHAT TO DO AND NOT DO WHEN DEVELOPING PARTNERSHIPS

RT-19A proved to be an excellent opportunity to learn what to do and not do when developing partnerships. At the year-end meeting in Washington there was considerable discussion of the partnerships, with all of the participating PIs having suggestions for what to do and not do. The following combines their suggestions with information learned in the interviews that provided the basis for the case studies above.

Choosing partners

- Partnering should be a win-win situation with each school having something unique to offer the other.
- The best partnerships may be between very different institutions—for example, a school that excels in undergraduate education in engineering with a school that has a graduate program in systems engineering, or a small liberal arts school with a large land-grant university.
- Another promising model is to have specialty schools or programs provide services to multiple organizations (e.g., systems assurance provided by one institution to many). For example, there could be schools that act as contractors for subsystems and process elements (such as assurance), with the lead school calling for "bids" for work.
- Faculty members in the different institutions should have complementary knowledge/skills and complementary research interests to ensure that all areas of expertise are covered within the collaboration.
- The students must see the collaboration as filling a real gap/need for their teams, not something they could do without the partner.
- It may be easiest to partner with schools that are in close proximity so students can meet face-to-face at the beginning and occasionally thereafter.

Funding partners

- Partnerships should not be between institutions where one (or both) have institutional barriers to funding outside groups. It may be helpful to create some sort of "systems engineering" relationship to allow money to flow to the partnering school.
- Some flexibility should be built into the project and funding schedule to allow for overcoming these barriers.

Timing

- Planning with partner schools should start early, at least in the spring prior to the capstone course.
- Students should also be recruited early, preferably in the spring prior to the capstone.
- All partners need to be able to work according to the same timetable or schedule, i.e., the semester schedule and the project timeline.

Partner roles

- It is beneficial to the relationship if the partnering schools can hold a "meet and greet" session with students, mentors, and faculty to promote the collaboration.
- For the best final result, subsystems being built by different partners should be interdependent. In other words, although it might be tempting to completely separate tasks or subprojects, they need to stay integrated for the partnerships to work.

Oversight

- The partners' expectations of the mentors, customers, and funders should be laid out at the beginning of the project.
- It may be helpful to establish a project board of all stakeholders to plan and then monitor the project.

- It may be helpful to develop a grading rubric for effective collaboration with students at other schools.
- Partner schools should establish where the resources are going to reside (i.e., location of personnel and equipment).
- Projects should not be considered complete (i.e., student receive credit) before all the tasks are completed, including devices returned, documents returned, surveys finished, etc.

Student communication/collaboration

- It cannot be assumed that students are spontaneously collaborative. Instead, mutual understanding and continuous communication between collaborative teams may need to be encouraged, as early as possible.
- There should be a solid communication infrastructure between the partnering schools, and communications should not be restricted to one form or another.

Mentors

- Mentors are important and need to be brought into the partnership early and often.
- Be sure mentors interact with students in the partner schools as much as with students in the lead institutions.

Curriculum

- Faculty should encourage (and practice) the same teamwork practices they expect their students to use.
- Faculty teaching the capstone courses should talk to each other regularly regarding project progress / issues/ deliverables so that they are on the same page. Where possible, curriculum should be shared or co-developed.
- Courses should be structured to ensure maximum student interaction between or across institutions.

8.0 CONCLUSION AND RECOMMENDATIONS

Based on site visits to RT-19 institutions in 2010-2011, the DoD sponsors developed a list of nine promising practices that they believed would lead to improved learning outcomes and prototype development. Most of those practices were implemented and did indeed appear to help faculty make best use of resources and improve the capstone experience for students. We encourage faculty to adopt these practices in future systems engineering capstone projects. (See Table 32 for a breakdown of the promising practices adopted by each school.)

Partnerships were new to RT-19A. Our experience with different forms of partnerships leads us to conclude that this is a fruitful way to promote and disseminate the practice of multidisciplinary systems engineering capstone experiences. Partnering between schools provides several benefits:

- Schools that do not have systems engineering gain access to schools with systems engineering expertise
- Students at schools with only one engineering major are able to work in multidisciplinary teams
- Students have access to a wider variety of student skills and abilities when forming teams
- Students are exposed to a wider diversity of teammates
- Students are exposed to a wider variety of mentors
- Students at civilian schools gain access to military commands and to DoD problem areas
- Students learn the benefits and difficulties of working at a distance

However, such partnerships introduce new challenges:

- Students at different schools may have different academic calendars, be in different time zones, and therefore have difficulty coordinating schedules, meetings, delivery timelines, etc.
- Students may have difficulty communicating at a distance
- Students who cannot meet face-to-face may have difficulty learning trust, determining roles, and developing collaborations

All of these challenges make the projects more realistic, as modern engineering practice often includes partnering with colleagues in remote locations. Nevertheless, greater challenges imply greater risks, often mitigated by increased faculty supervision and guidance. There were several different models adopted by the participating schools, and each school needs to choose the one that works most effectively for it.

Most faculty who participated in these multi-school partnerships reported that they enjoyed the experience but felt that they worked harder than they did on “normal” capstone projects. Rather than develop school-to-school partnerships, an alternative would be to facilitate ad hoc partnerships between student groups in different schools through an open model of project proposal, sponsorship, selection and execution. We therefore propose a central repository where:

- Sponsors propose projects
- Students apply for participation on projects
- Sponsors select students for project teams, perhaps with some assistance from faculty

All of these actions could take place with little or no faculty involvement. Each student needs to find someone at their school to approve their participation (that is, give them credit for their work) and then to provide any needed guidance and assessment of their work. Additionally, until they became experienced with this process, sponsors need assistance in creating realistic project proposals and in selecting appropriate students. Similarly, students need some assistance in using this system. The only problem with this strategy is that it ignores an important purpose of capstone projects, namely their role within engineering curricula, so systems engineering education would have to be built in locally.

Stevens has decided to embark on a pilot project to test this concept with a few sponsors, schools, and students. The PI at Stevens, along with some collaborating faculty, is assisting sponsors in writing proposals and in forming teams. They are also providing one faculty advisor to each project to make sure that students get the guidance they need. That advisor will work with other faculty, as needed, in assessing student performance. At the end of the pilot the team of project faculty advisors will write a set of guidelines to be used in future versions of this system.

Institution	Fall lecture/spring design	Cross-disciplinary teams	Regular involvement of mentors	Civilian schools establish relationship with nearby commands	Creative use of DoD mentors	Structured design reviews with mentors	Systems engineering graduate students as project advisors	Creative imposition of technical, budget and schedule constraints	Established relationship with ROTC
Air Force Academy				N/A					N/A
Auburn									
Coast Guard Academy				N/A					N/A
Connecticut College									
Military Academy				N/A					N/A
Missouri University of Science and Technology									
Naval Academy				N/A					N/A
Smith College									
Southern Methodist University									
Stevens Institute									
Sweet Briar						N/D			
University of Hawaii									
University of Virginia									

Table 32: Promising Practices by School

APPENDICES

APPENDIX A: BREAKDOWN OF STUDENTS BY INSTITUTION

[Data as reported from PI fall surveys, 2011]

Institution	Fall	Spring
Air Force Academy	5	5
Auburn	29	13
Coast Guard Academy	42	66
Connecticut College	2	12
Military Academy	4	4
Missouri University of Science and Technology	46	47
Naval Academy	38	45
Smith	22	22
Southern Methodist University	48	64
Stevens Institute	24	23
Sweet Briar	4	4
University of Hawaii Manoa	24	19
University of Virginia	18	15
Total	306	339

APPENDIX B: MENTORS BY INSTITUTION

University	Mentor name	Mentor type	Organization	Area of expertise
Air Force Academy	Bryan Cooper, Instructor	Internal institutional	US Air Force Academy	Electrical engineering, power systems
Air Force Academy	Colonel Brett Lloyd	DoD-assigned	USAF Reserve	
Air Force Academy	Engineers	Industry	American Electric Vehicles	Electrical engineering
Auburn	Jeremy Barnes, Teaching Assistant	Internal institutional	Auburn	Systems Engineering
Auburn	William Simon, Research Assistant & Graduate Student	Internal institutional	Auburn	Computer Science
Auburn	Advisory board[3]	Industry	NASA, Missile Defense Agency, US Army Aviation and Missile Command, Auburn Huntsville Research Center, Frontier Technology[4]	Systems engineering
Coast Guard Academy	Chris Lund, Research Engineer	Internal institutional	USCG R&D center	Civil Engineering
Coast Guard Academy	Major Georges Dosso & several other	DoD-assigned	USCG R&D center	

[3] Auburn's Advisory Board as reported to systems engineering - ISNY on October 2011 included: Tom Channell (US Army Aviation and Missile Command), Ms. Patricia Gore, (Missile Defense Agency), Lavan Jordan (Frontier Technology), John Olson (NASA Headquarters Office), and Rodney L. Robertson (AU Huntsville Research Center).

[4] PI listed these as industry mentors, not DoD mentors.

	researchers			
Coast Guard Academy	Scot T. Tripp, Program Manager	Internal institutional	USCG R&D center	Ocean Engineering
Coast Guard Academy	Ken Kennedy	Industry	Retired, Hamilton Sundstrand	Turbine expert
Coast Guard Academy	Brent Fike	Internal institutional	USCG R&D center	Mechanical Engineering
Military Academy	Bill Crawford, Engineer	DoD-assigned	AMRDEC	Systems engineering
Military Academy	Paul DiNardo	DoD-assigned	AMRDEC	
Military Academy	David Jacques	DoD-assigned	AMRDEC AFIT	
Military Academy	Ed Winkler	Industry	The Boeing Company	Systems engineering
Missouri University of Science and Technology	Al Brown	Industry	Boeing	Systems Engineering
Missouri University of Science and Technology	Paul Barnes, Chief, Power Components	DoD-assigned	Army Research Laboratory	Electrical, Materials
Missouri University of Science and Technology	Robert Mantz	DoD-assigned	Army Research Laboratory	
Missouri University of Science and Technology	Mike McClelland	Industry	Boeing	Systems Engineering
Missouri University of Science and Technology	Lou Pape, Associate Technical	Industry	Boeing	Systems Engineering

	Fellow			
Missouri University of Science and Technology	Nancy Pendleton	Industry	Boeing	Systems Engineering, Electrical Engineering
Missouri University of Science and Technology	Rob Simons	Industry	Boeing	Systems Engineering, Electrical Engineering
Missouri University of Science and Technology	Robert Scheurer, Systems Engineering Function	Industry	Boeing	Systems Engineering, Electrical Engineering
Missouri University of Science and Technology	Dale Waldo	Industry	Boeing	Systems Engineering, Electrical Engineering
Missouri University of Science and Technology	Neil Whipple, Engineer	Industry	Boeing	Avionics Integration
Missouri University of Science and Technology	Nancy Pendleton, Director in Advance Design	Industry	Boeing	Electrical Engineering
Naval Academy	Greg Hanswon	Industry	Aqua Sun	Water purification technology
Naval Academy	John Schedel, Project advisor; Capstone course instructor	Internal institutional	US Naval Academy	Mechanical
Naval Academy	CDR G.P. Sandhoo	DoD-assigned	DISA/OSD-ASD (R&E)	
Naval Academy	Kim Watkins	DoD-assigned	OSD (AT&L) reserve support	Systems Engineering

				Electrical Engineering CS&E
Naval Postgraduate School	Kim Watkins	DoD-assigned	OSD (AT&L) reserve support	Systems Engineering Electrical Engineering CS&E
Southern Methodist University	Michael D. Woodman, Director, Defense Solutions	DoD-assigned/Industry	Design Interactive, Inc.	Industrial (Interactive Simulation)
Southern Methodist University	Pete Muller	Industry	Potomac Training Corporation	Immersive training environments
Southern Methodist University	Michael F. Siok	Industry	Lockheed Martin Aeronautics Company	Defense contracted system development and analysis
Southern Methodist University	Kendy Vierling	DoD-assigned	MAGTF Training Simulations Division	
Southern Methodist University	Kim Watkins	DoD-assigned	OSD (AT&L) reserve support	Systems Engineering Electrical Engineering CS&E
Southern Methodist University	Tim Woods	Industry	Lockheed Martin Aeronautics Company	Defense contracted system development and analysis
Stevens	Tom Newby	Industry	Buro Happold Engineers	Disaster relief

Stevens	George Isabella, Manager; Test Equipment Engineering / Defense Specialties Engineering	DoD-assigned	BAE Systems	Manager; Test Equipment Engineering / Defense Specialties Engineering
Sweet Briar	Kim Watkins	DoD-assigned	OSD (AT&L) reserve support	Systems Engineering Electrical Engineering CS&E
Sweet Briar	Colonel Nancy Grandy	DoD-assigned	Navy Ordnance (NAVsystems engineering)	
Sweet Briar	Bill Campbell	DoD-assigned	Navy Ordnance (NAVsystems engineering)	
Sweet Briar	Panel of engineers	Industry	Northrup- Grumman	Systems engineering & communication systems
University of Hawaii	Dr. Allen Nikora	Industry	NASA Jet Propulsion Laboratory's Process and Product Quality Assurance group (5124) and Assurance Research group[5]	Software intensive systems assurance
University of Hawaii	Joel Wilf	Industry	NASA Jet Propulsion Laboratory's Process and Product Quality Assurance group (5124) and Assurance Research group[6]	Software intensive systems assurance

[5] PI listed these as industry mentors, not DoD mentors.
[6] PI listed these as industry mentors, not DoD mentors.

University of Hawaii	Michael D. Woodman, Director, Defense Solutions (formerly US Marine Corps)	Industry	Design Interactive, Inc.	Industrial (interactive simulation)
University of Virginia	Bill Campbell, Systems Engineer	Industry	Combat Direction Systems Activity (CDSA) Dam Neck, Virginia Beach VA	systems engineering & communication systems
University of Virginia	Kim Watkins	DoD-assigned	OSD (AT&L) reserve support	Systems Engineering Electrical Engineering CS&E
University of Virginia	Colonel Nancy Grandy	DoD-assigned	Navy Ordnance (NAVsystems engineering)	
University of Virginia	Bill Campbell, Systems Engineer	DoD-assigned	Navy Ordnance (NAVsystems engineering)	
University of Virginia	Panel of engineers	Industry	Northrup-Grumman	Systems engineering & communication systems

BIBLIOGRAPHY

National Defense Industrial Association systems engineering Division Task Group . (2006). *Top five systems engineering issues within DoD and Defense Industry.*

National Defense Industrial Association systems engineering Division. (2010, July). *Top systems engineering Issues in DoD and Defense Industry .*

Rosato, D., Braverman, B., & Jeffries, A. (2009, November). The 50 best jobs in America. *Money Magazine* , pp. 88-96.